SNS Drift Tube Linac PDR September 26 and 27, 2000

September 26 - MPF-6, Orange Box conference hall, 8 am to 5 pm

September 27 - MPF-1, Rosen auditorium, 8:30 am to 3 pm

September 26

Introduction (Kirk Christensen)	**8:00-8:15**
Charge to committee Design review process Project scope and deliverables	
Physics design (Jim Stovall)	**8:15-9:15**
Performance/Design criteria Design constraints Beam physics issues Diagnostics description and layout	
Cavity design (Jim billen)	**9:15-9:45**
Cell design procedures Frequency budget Low power (cold model) status	
DTL mechanical system overview (Tom Ilg)	**9:45-10:15**
Break	**10:15-10:30**
Drift tube design (Ray Valicenti) Design, requirements, and features PMQ design Fabrication	**10:30-11:30**
Electro-magnet Dipole design (Ted Hunter)	**11:30-11:45**
Beam position monitor drift tubes (Jim O'Hara)	**11:45-12:00**
Lunch	**12:00-12:45**
RF structure mechanical design (Tom Ilg) Tanks Post couplers Slug tuners Endwalls	**12:45-1:15**
Iris waveguide mechanical design (Richard Lujan)	**1:15-1:45**
Water system overview (John Bernardin)	**1:45-2:00**
Vacuum system overview (John Bernardin)	**2:00-2:15**

Agenda (con't)

Thermal analysis (Lucie Parietti)	**2:15-3:15**
Drift tubes Tanks Post couplers Slug tuners	
Break	**3:15-3:30**
Thermal analysis (Snezana Konecni) Endwalls Iris waveguide	**3:30-4:00**
Dynamic analysis (Steve Ellis)	**4:00-4:30**
Support structure design (Tom Ilg)	**4:30-5:00**

September 27

Support structure analysis (Matt Fagan)	**8:30-9:00**
DTL interfaces (Tom Ilg) MEBT Intertank regions and Diagnostics CCL 402.5 MHz window Endwall valve	**9:00-9:30**
DTL alignment (Bill Rodriguez) Alignment method Cold model alignment results	**9:30-10:00**
Break	**10:00-10:15**
DTL assembly (Arthur Guthrie)	**10:15-10:30**
DTL installation at ORNL (Arthur Guthrie)	**10:30-10:45**
Costs and schedule (Arthur Guthrie)	**10:45-11:15**
Summary (Kirk Christensen)	**11:15-11:30**
Lunch	**11:30-12:30**
Committee caucus (review committee only)	**12:30-2:30**
Out briefing	**2:30-3:00**

SNS Drift Tube Linear Accelerator
Preliminary Design Review
September 26 & 27, 2000

DTL Physics Design Basis

J. Stovall & J. Billen

DTL Frequency

- **CCL: 805 MHz chosen for historical reasons**
  - CCL represented 98% of the linac
  - klystrons at this frequency considered mature & cheap
  - arguments are no longer applicable
- **DTL frequency must be a subharmonic of 805 MHz**
  - i.e. 805, 402, 268, 201, 161
- **Large frequency jumps are generally bad**
  - cause very nonlinear longitudinal beam dynamics
  - complicate transverse matching
  - result in large charge densities in the CCL
- **ZT^2 is independent of frequency for constant r_{bore}**
  - $r_{\mathbf{bore}}$ is a function of the beam current & magnet strength

DTL Frequency = 402.5 MHz

- **402.5 MHz drift tubes are large enough to accommodate PMQs**
  – limited demonstration on a few linacs
- **402.5 & 201.25 MHz drift tubes would accommodate a funnel**
  – required historically
- **268.3 MHz drift tubes would accommodate EMQs**
  – probably a better choice for several reasons

DTL Energy

- **W_0=2.5 MeV**
  - higher energies (7 MeV) are better
  - forced down by chopper length & dump power dissipation
- **W_{final}= 87 MeV**
  - matches CCL efficiency
  - convenient for power partitioning
  - funnel no longer required

DTL Focusing Lattice

- **Transverse focusing compensates**
  - space charge forces &
  - rf defocusing
- **Beam current = 52 mA peak**
  - performance must be current independent
- **Options studied: ($\beta\lambda_{402.5}$)**
  - 2 $\beta\lambda$, +-
  - 4 $\beta\lambda$, ++--
  - 6 $\beta\lambda$, ++0--0

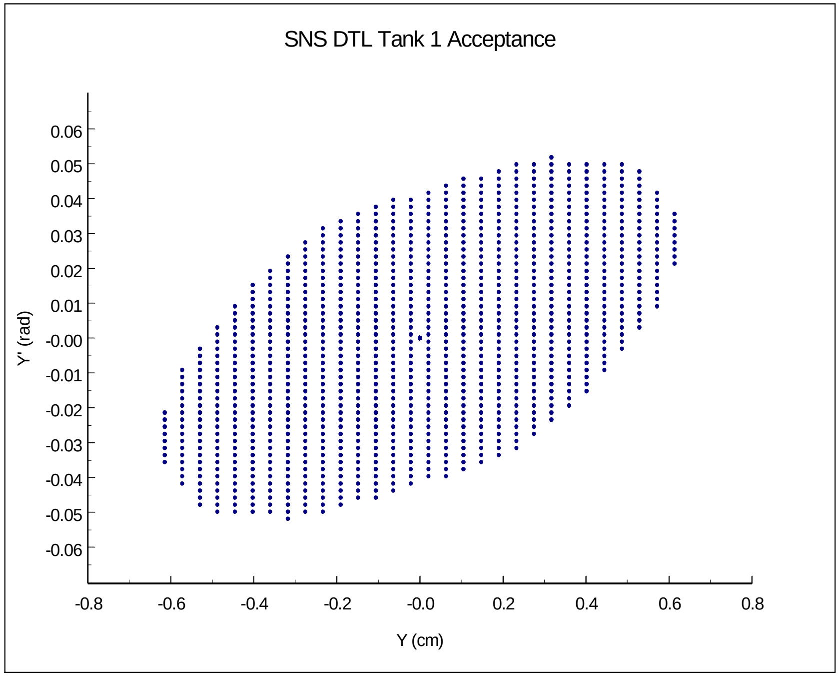
6 $\beta\lambda$ FFODDO Lattice Selected

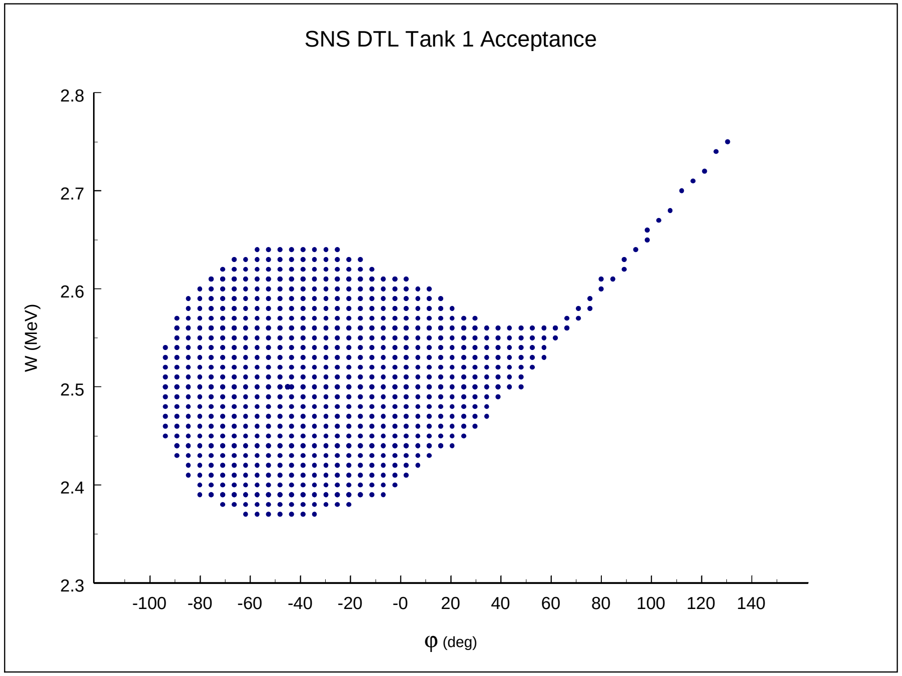
- **Provides strong focusing**
- **Accommodates steering & diagnostics in empty drift tubes**
- **Closely matches CCL lattice of 13 $\beta\lambda_{805}$**
  - 6 $\beta\lambda_{402.5}$ = 12 $\beta\lambda_{805}$
  - DTL-CCL match is smooth & nearly current independent
- **PMQs throughout**
  - constant GL, 3.7 kG/cm, R_{bore}=1.25 cm
- **Accommodates 1 $\beta\lambda_{402.5}$ inter-tank spacing**
  - small mismatch due to missing gap
  - steering provided elsewhere
- **E_0 is ramped in tanks 1, 2 & 6 to adiabatically match the beam longitudinally (ϕ_s in tank 6)**

Commissioning/Operations Beam Measurements

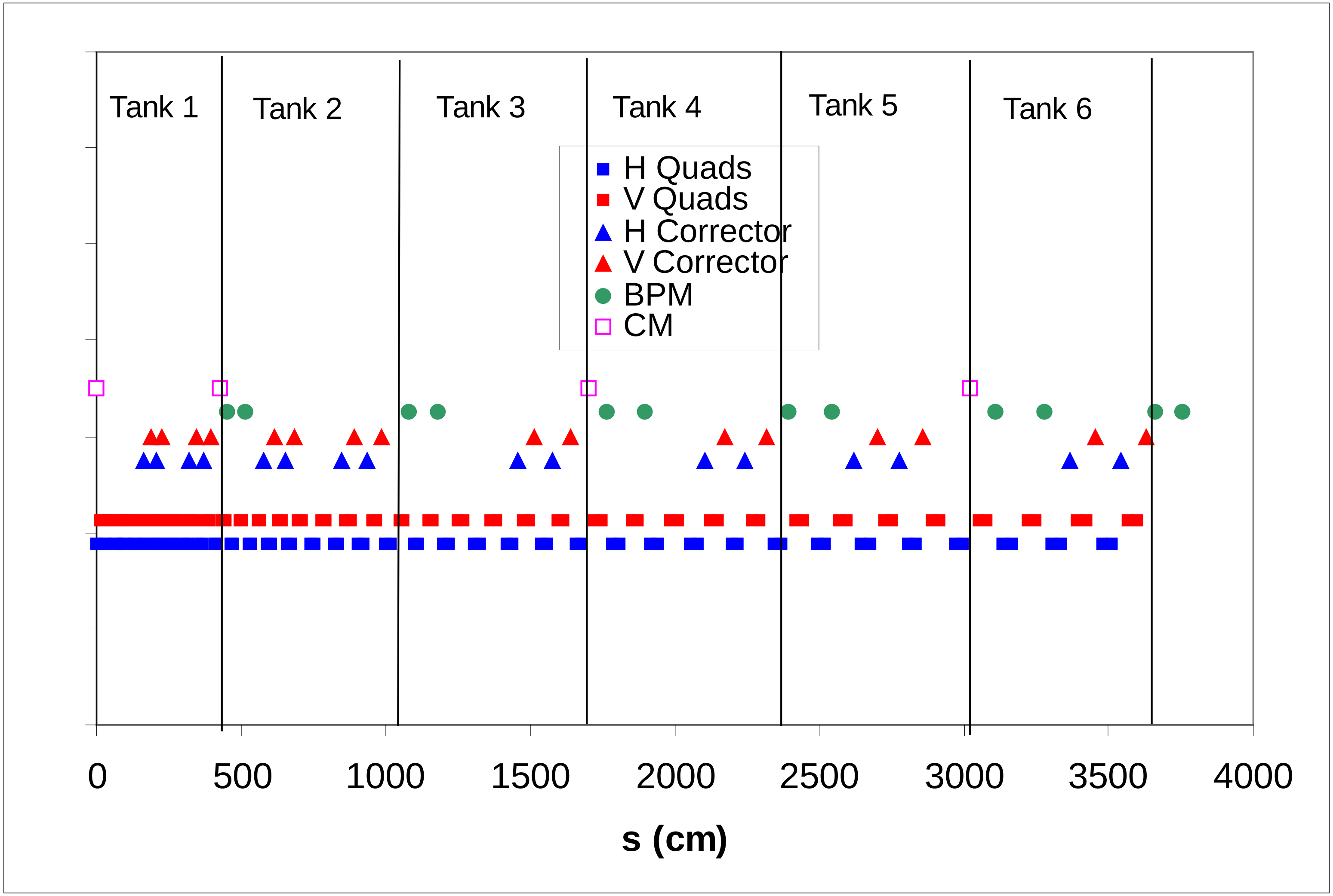
- **Transverse**
  - Acceptance
  - Steering
  - Matching
  - Profile
  - Transmission
- **Longitudinal**
  - Central energy
  - Phase acceptance
  - Amplitude acceptance

DTL Tank 1 Acceptance

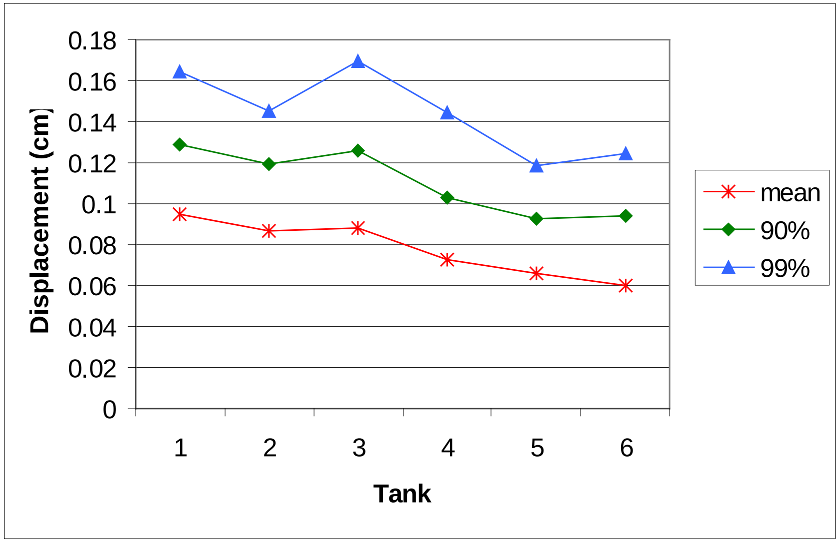


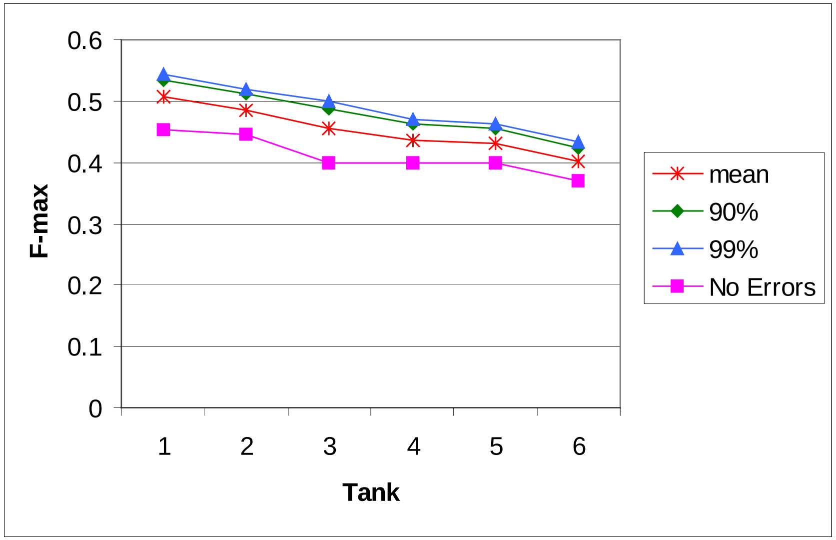


Proposed Dipole & BPM Locations



Steering Solution





DTL Inter-Tank Diagnostics

Tank	1	2	3	4	5
W_{out} (MeV)	7.5	22.8	39.8	56.6	72.5
Toroid	X	X	X	X	X
Wire Scanner	X	X	X	X	X
Faraday Cup	X	X	X	X	X
Degrader	X	X	X	X	X
Harp	-	-	X	-	-
Valve	-	X	X	X	X

Variable Quadrupole Options

- **FFfDDd**
  - low field correctors
- **Full strength EMQ's**
  - in tanks 3, 4, 5, & 6
- **Tape wound EMQ's**
- **EMQ's between tanks**
- **EMQ's + PMQ's in the same drift tube.**

SNS Drift Tube Linear Accelerator Preliminary Design Review September 26 & 27, 2000

DTL Physics Design

James H. Billen

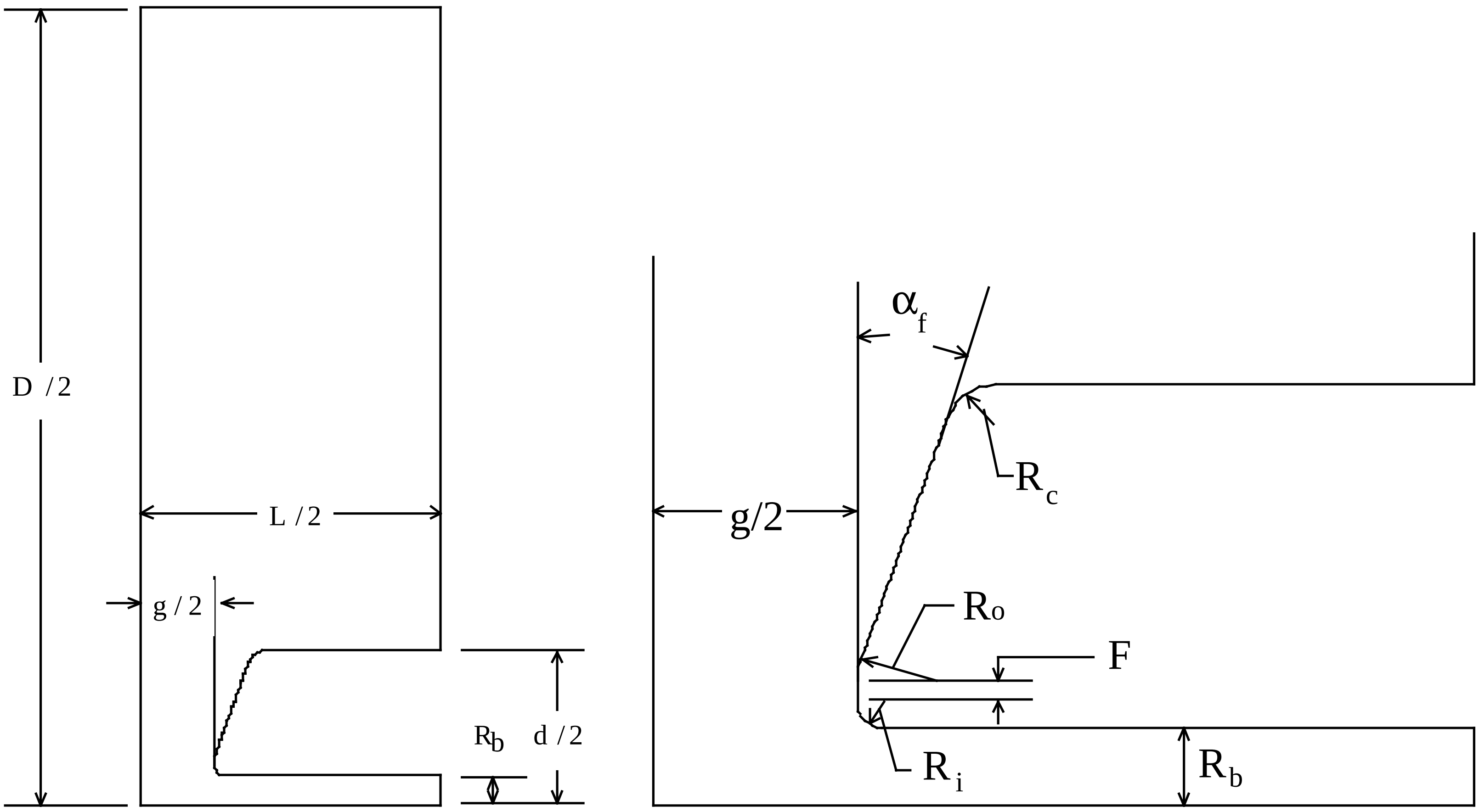
Outline

- **Review of the design**
- **Cell design procedure for the drift-tube linac**
- **Frequency budget and tank radius adjustment**
- **Low-power aluminum model**

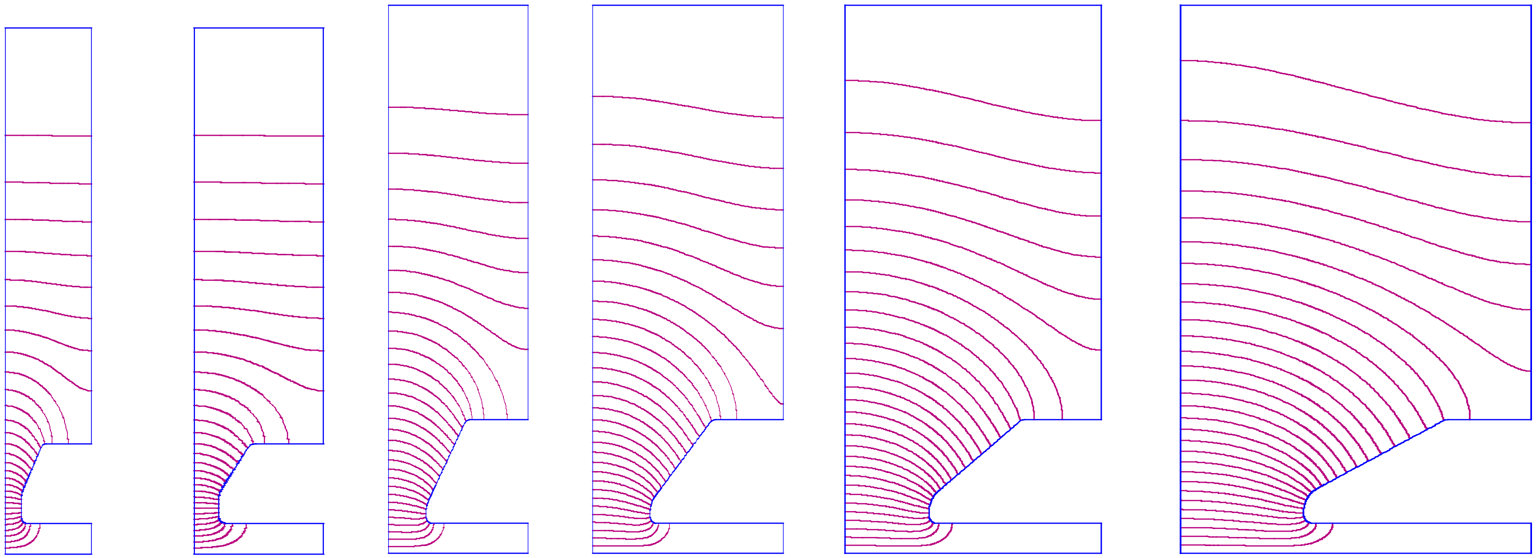
Drift-Tube LINAC Properties

- Energy range: 2.5 MeV (β = 0.073) to 86.8 MeV (β = 0.403).
- Six tanks, each with a 402.5-MHz, 2.5-MW klystron ($\leq$2.0 MW avail.).
- Spacing of 1 $\beta\lambda$ between tanks.
- Total Length is 36.5 m (tank 1 is 4.1 m, others are 6.1 to 6.4 m).
- Peak beam current I_{Beam} = 52 mA.
- Peak surface electric field is limited to 25.3 MV/m (1.3 Kilpatrick).
- Nominal accelerating field E_0 = 3.6 MV/m. (Ramped field in tanks 1, 3, and 6; peak E_0 = 3.77 MV/m at the end of tank 6.)
- Bore radius R_b = 1.25 cm.
- Average shunt impedance ZT^2 = 40 MΩ/m for all expected losses.
- FFODDO PMQ lattice (every third drift tube contains no quadrupole).
- Post-coupler stabilized (places limits on drift-tube-to-wall spacing).

Geometric Parameters in a DTL Cell



SUPERFISH Cavities at Tank Midpoints



0.09	0.17	0.25	0.31	0.35	0.39	← β
1.93	3.27	3.60	3.60	3.60	3.68	← E_0
0.85	1.26	1.21	1.23	1.18	1.23	← E_K
0.68	0.84	0.82	0.80	0.78	0.75	← T

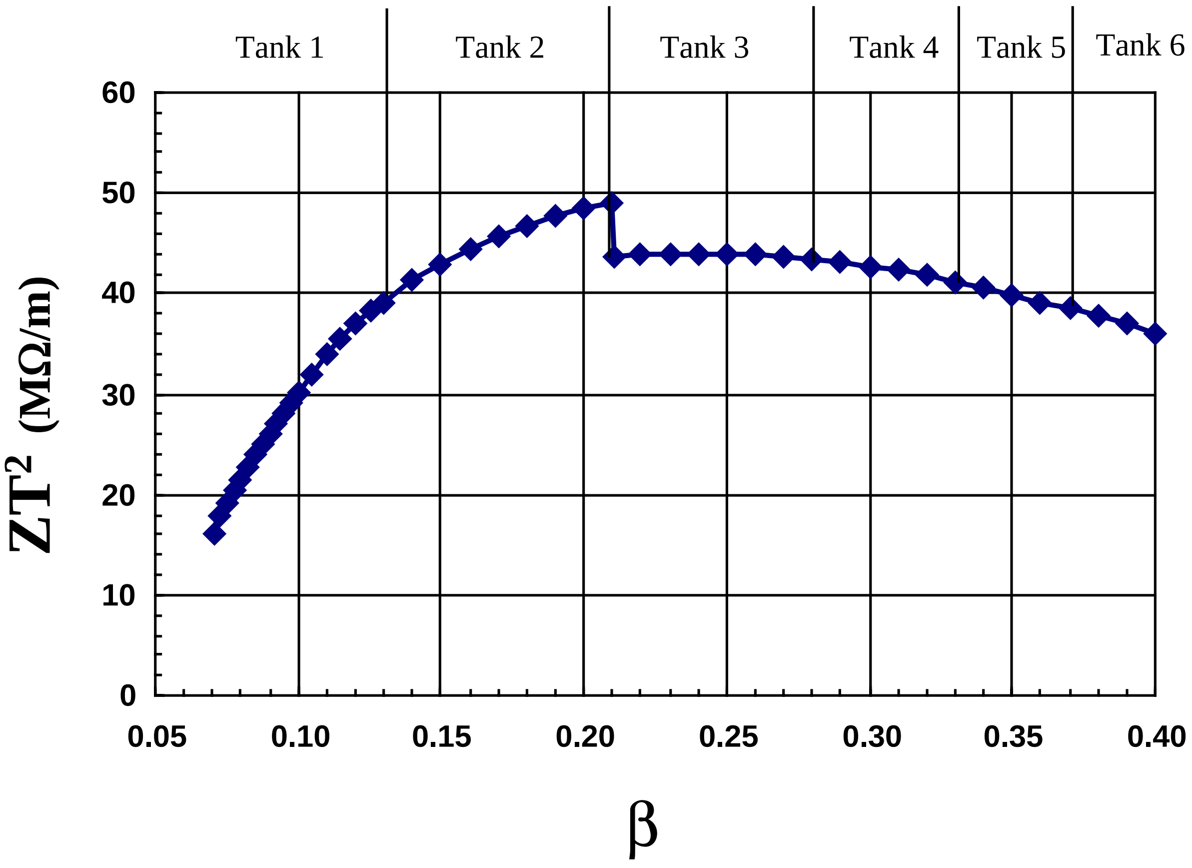
DTL Cell Design

- **Certain dimensions are fixed (or limited) by design criteria:**
  - Bore radius = 1.25 cm.
  - Drift-tube-to-wall distance $\approx 0.9 \times \lambda/4$.
  - Drift tubes must accommodate cooling passages and PMQs.
- **We optimize the rf cavity shape for highest ZT^2 at both ends of a range of velocity β by varying a few dimensions (e.g. drift-tube diameter, face angle).**
- **One dimension (the gap between noses) is adjusted to achieve resonance at the desired frequency.**
- **Linearly interpolate cell dimensions between the optimization points.**

DTL Parameters

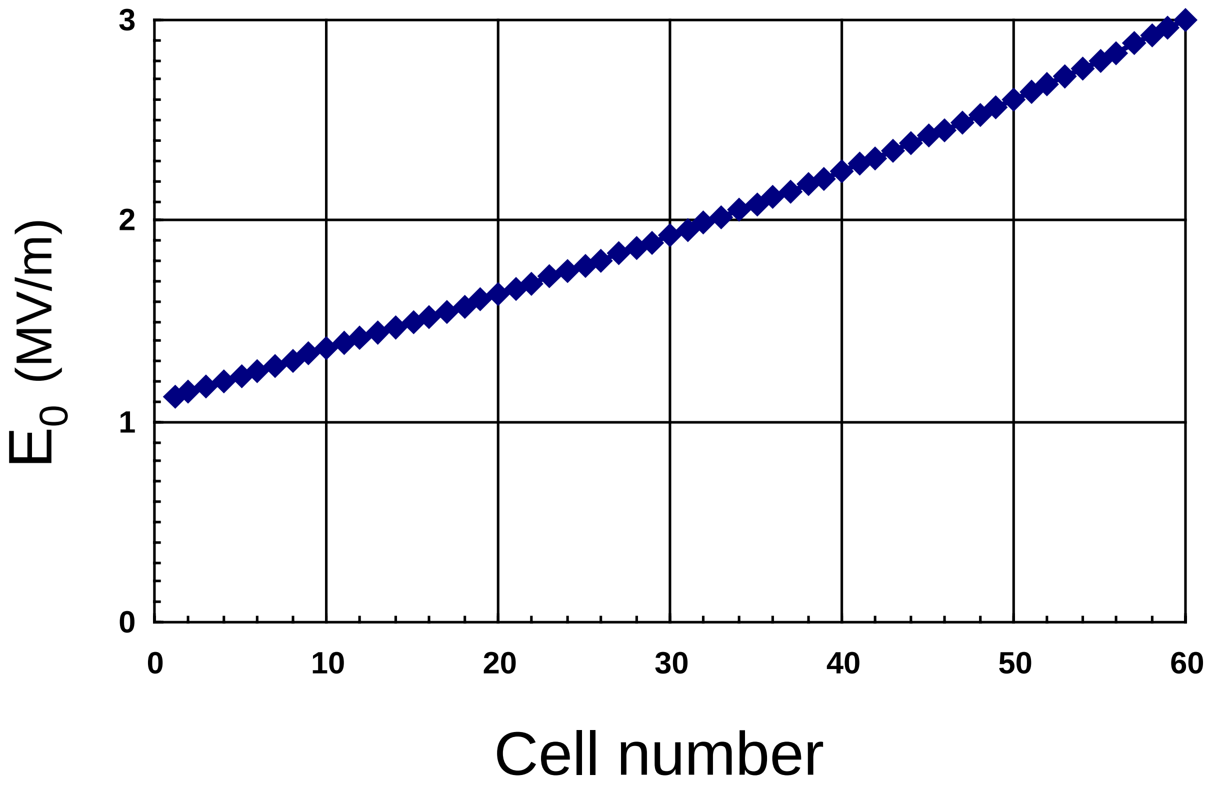
Tank number	1	2	3	4	5	6
Total length (m)	4.15	6.06	6.32	6.41	6.30	6.34
Number of cells	60	48	34	28	24	22
Final energy (MeV)	7.5	22.8	39.8	56.6	72.5	86.7
Cu + Beam Power (MW)	0.53	1.64	1.93	1.93	1.87	1.88
Tank diameter, D (cm)	43	43	45	45	45	45
Drift-tube diameter, d (cm)	9	9	11	11	11	11
Stem diameter (cm)	1.9	1.9	3.2	3.2	3.2	3.2
Corner radius, R_c (cm)	0.5	0.5	0.5	0.5	0.5	0.5
LE face angle, α_f (deg)	3.6	20.6	31.4	43.1	52.1	59.2
HE face angle, α_f (deg)	20.9	56.2	42.8	51.8	59.0	64.3
LE inner nose radius, R_i (cm)	0.179	0.317	0.350	0.350	0.350	0.350
HE inner nose radius, R_i (cm)	0.292	0.350	0.350	0.350	0.350	0.350
LE outer nose radius, R_o (cm)	0.506	0.950	1.050	1.050	1.050	1.050
HE outer nose radius, R_o (cm)	0.875	1.050	1.050	1.050	1.050	1.050
LE flat length, F (cm)	0.062	0.376	0.0	0.0	0.046	0.125
HE flat length, F (cm)	0.363	0.500	0.0	0.043	0.122	0.182

DTL Shunt Impedance



Tank 1 Field Distribution

Ramp is linear with β (not cell number).



Tank Radius Compensates for Known Frequency Effects

- **Using the Tank 1 low-power model as an example, we start with Superfish-designed cells that have diameter D = 43 cm.**
- **Computed frequency shifts add up to +2.792 MHz and include:**
  - Stems +1.505 MHz
  - Post couplers +0.241 MHz
  - Half of tuner range +1.046 MHz
- **For the low-power model, we ignore the effects of holes in the wall. High-power tanks will include corrections for pumping grills.**
- **Tuning rate for changes in tank radius is –11.845 MHz/cm.**
- **The radius must be <u>increased</u> 0.2357 cm to lower the frequency.**
- **Adjusted tank diameter D = 43.4715 cm.**

Frequency Budget

- Tank diameter has already been adjusted to account for known frequency shifts, including half the 2.1-MHz slug-tuner range.
- The 8 slug tuners per tank must have enough range to correct for all possible frequency errors resulting from manufacturing tolerances.
- Contributions to frequency errors near the ends of tank 1:

Dimension	Tolerance (mm)	Frequency Shift (kHz)	
		β=0.08	β=0.14
Tank diameter	±0.406	±242	±240
Drift-tube diameter	±0.076	±79	±10
Drift-tube gap	±0.025	±448	±244
Stem diameter	±0.355	±63	±43
Post couplers	±0.355	±140*	±140*
Total (all with like sign)		±972	±677

* Estimate from previous DTLs, effect mainly from tip-to-drift-tube spacing.

Tank 1 Low-Power Model

Low-Power Model Measurements

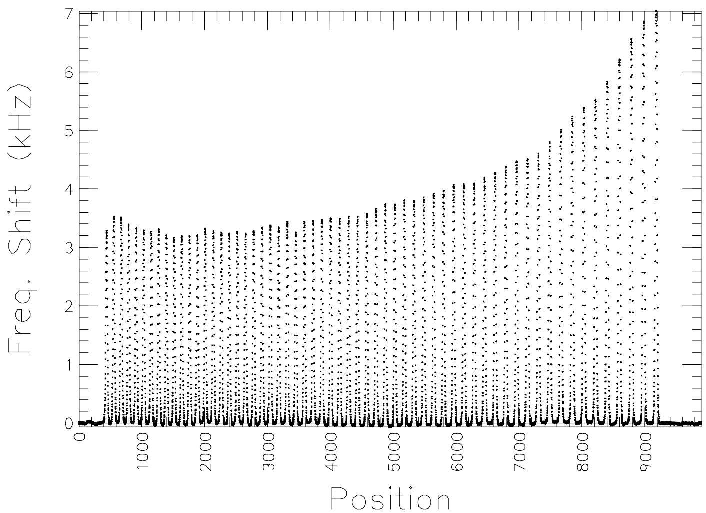
- **Preliminary measurements (before fields have been stabilized):**
  - Frequency range of slug tuners is ~2 MHz as expected.
  - TM_{010} frequency is within range of the slug tuners.
  - Bead-perturbation measurements without post couplers show tilt sensitivity slope of ~ 820 %/MHz.
- **Work in progress :**
  - Tune post couplers to stabilize the field.
  - Adjust post-coupler asymmetry to set the field distribution.
  - Measure the frequency effect of pumping slots.
  - Adjust the iris for desired coupling to external power supply.

Bead Perturbation Technique

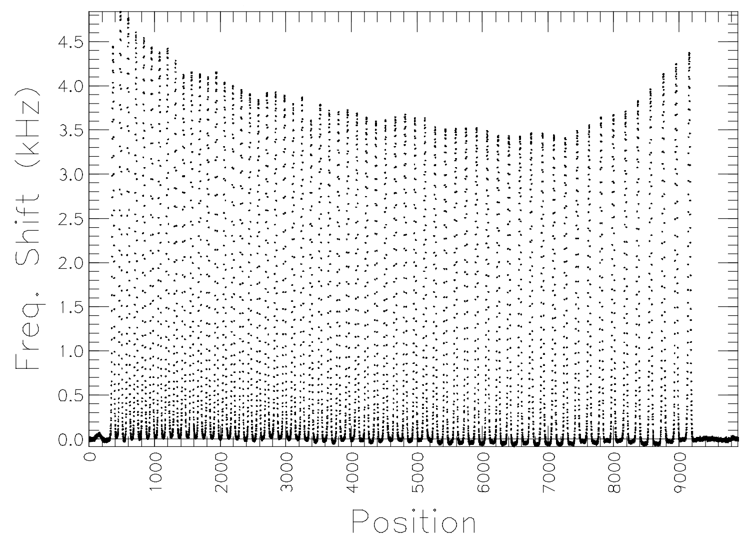
- **Measurement data consists of frequency shifts versus longitudinal position of a metal sphere pulled through the bore of cavity. (Position is inferred from time for a constant velocity bead.)**

- **Frequency shifts (typically a few kHz) are proportional to the square of the electric field integrated over the volume of the bead.**

No end-cell perturbation



LE –50 kHz; HE +50 kHz



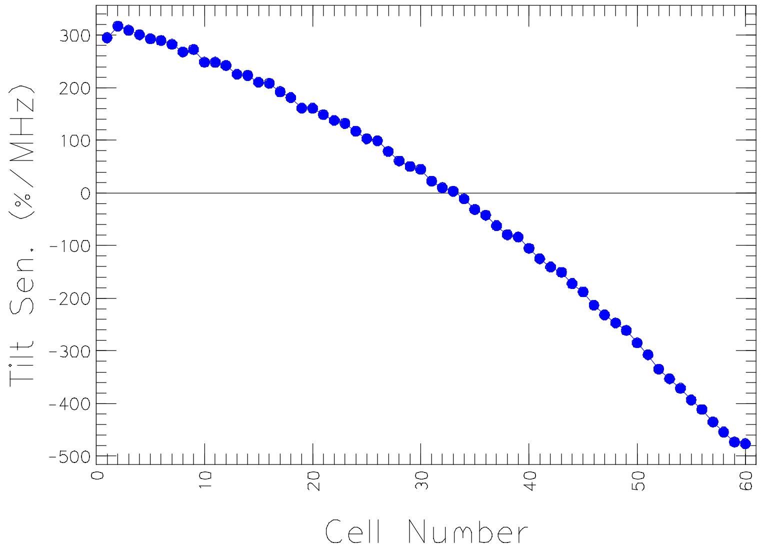
Tilt Sensitivity Measurements

- Measures the stability of the fields against frequency perturbations.

- For each cell:

$$\text{T.S.} = \frac{(E_0^- - E_0^+)}{1/2(E_0^- + E_0^+)} \longleftrightarrow \frac{1}{\Delta f^+ - \Delta f^-}$$

where E_0^+ is the field for frequency perturbation Δf^+, and
E_0^- is the field for frequency perturbation Δf^-.



SNS Drift Tube Linear Accelerator
Preliminary Design Review
September 26 & 27, 2000

DTL System

Overview

Tom Ilg

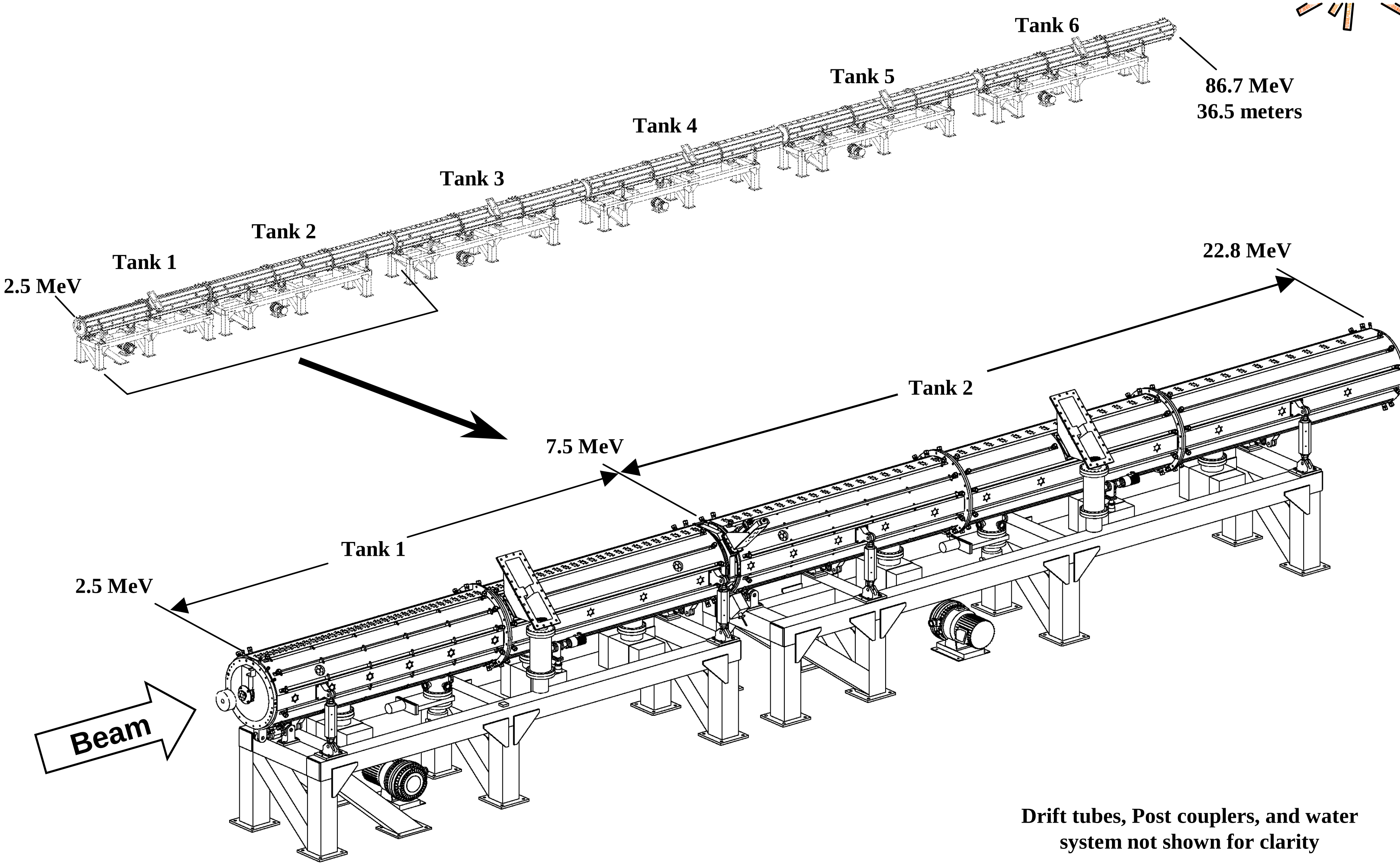
SNS DTL Design Team and Contributors

- Dan Richards
- Matt Fagan
- Arthur Guthrie
- Snezana Konecni
- Lucie Parietti
- Steve Ellis
- Bill Rodriguez
- Jim Billen
- Jim O'Hara
- Nathan Bultman
- Jim Stovall
- Art Romero
- Ray Valicenti
- Ross Meyer Jr.
- Paul Lopez
- John Bernardin
- Tom Ilg
- Lloyd Young
- Ted Hunter
- Braden Roller
- Bob Gillis
- Ivan Medalen
- Gerald Bustos
- Mike Hood

WBS 1.4.2 DTL System Scope & Deliverables

- **WBS 1.4.2 includes engineering, design, analyze, fabricate, assemble, test, tune, align, and deliver a 402.5 MHz, 86.8 MeV Drift Tube Linear accelerator**
  - WBS 1.4.2.1 Integration
  - WBS 1.4.2.2 DTL structure
    - » Tanks
    - » RF components
  - WBS 1.4.2.3 Drift tubes assemblies
    - » Drift tubes
    - » PMQ’s
    - » EMD’s
  - WBS 1.4.2.4 Vacuum system
  - WBS 1.4.2.5 Water system
  - WBS 1.4.2.6 Mechanical systems
    - » Support stand
    - » Alignment system
  - WBS 1.4.2.7 DTL Assembly
  - WBS 1.4.2.8 Installation (ORNL)
  - WBS 1.4.2.9 DTL Cold model

86.7 MeV DTL System



Drift tubes, Post couplers, and water system not shown for clarity

DTL Parameters and Features

- **402.5 MHz accelerating structure.**
- **Accelerates a H^- proton beam from the MEBT at 2.5 MeV to 86.8 MeV at the CCL.**
- **6 DTL tank assemblies with 1 $\beta\lambda$ spacing between.**
  - Total length of 6 tanks = 36.5 m
- **Each DTL tank uses one 402.5 MHz, 2.5 MW klystron.**
- **Accelerating gradient = 3.6 MeV/m, tanks 1, 2 and 6 are ramped.**
- **RF structure duty factor = 7.02%**
- **Drift tube and endwall bore radius = 1.25 cm**
- **210 drift tube assemblies with 140 Permanent Magnet Quadrupoles (PMQ) provide transverse beam focusing.**
  - Focusing lattice = FF0DD (every third drift tube does not contain a PMQ)
  - Magnet gradient = 3.7 kG/cm
  - Magnet strength = 12.95 kG
  - PMQ material = Sm_2CO_{17}
- **24 drift tubes with Electro-Magnet Dipoles (EMD) for transverse beam steering (4 per tank).**

DTL Parameters and Features (con't)

- **Water cooled system provides resonance frequency control.**
  - RF structure operating temperature ~ 80^0F
  - Each tank has it's own separate water-temperature based resonance control loop.
- **Vacuum system provides the necessary base pressure to satisfy RF operating and radiation activation requirements:**
  - Operating Base Pressure 1.8E-7 Torr (N_2)
    1.3E-6 Torr (H_2)
- **Elastomer o-rings (Viton) are used as vacuum seals, except for drift tube mounts which are metal vacuum seals.**
- **RF seals are metallic, silver plated Inconel and gold plated multi-contact bands are used.**
- **Post couplers are used to provide longitudinal electric field stability.**
- **Slug tuners are used to provide static frequency adjustment.**
- **Ridge loaded Iris waveguide provides RF power coupling.**

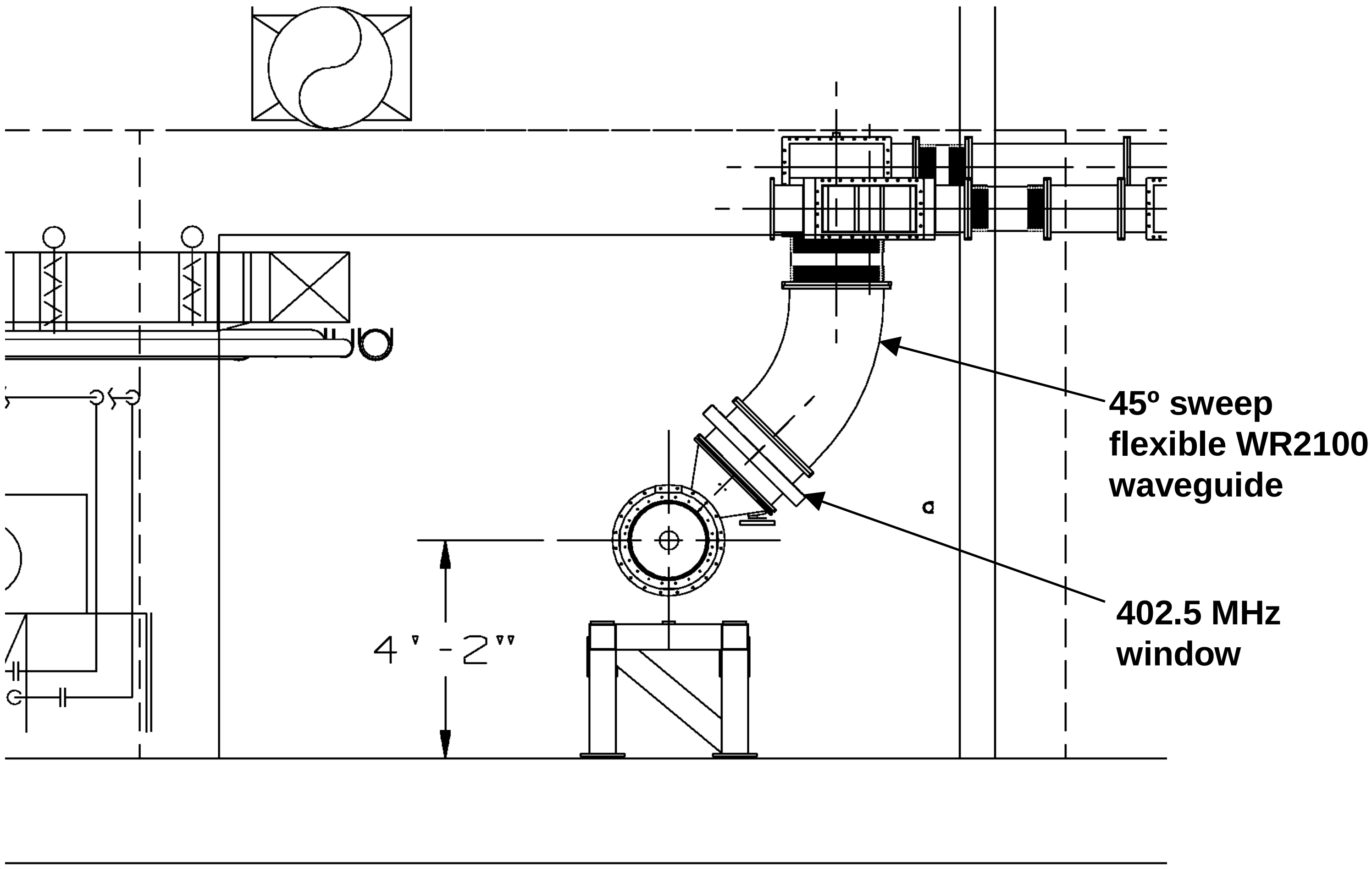
DTL Parameters and Features (con't)

- **Drift tubes magnet centers are aligned optically-mechanically using a laser tracker system. Laser targets are mounted on individual drift tubes and the endwalls.**
  - PMQ (drift tube) alignment budget ±.005" transverse
    ±.005" longitudinal
- **Tank to tank alignments are made optically-mechanically using a laser tracker system. Laser targets are mounted on the exterior of the upstream and downstream endwalls.**
  - Tank to tank alignment budget ±.005" transverse
    ±.005" longitudinal

DTL Mechanical Design Status

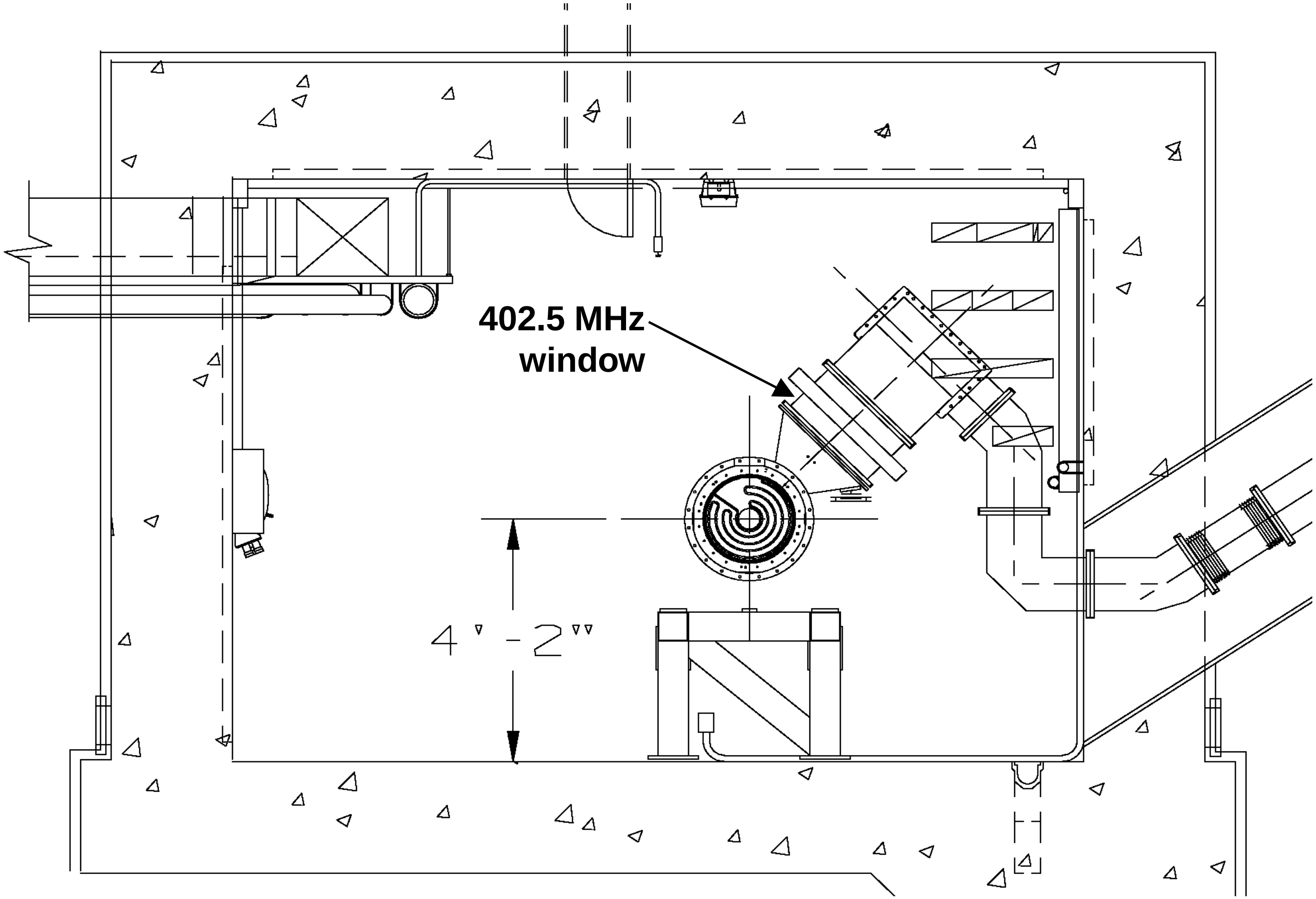
- **Physics design and drift tube tables (design spec. # 1.4.2-DS-01) have been completed and mechanical assembly layouts of all the tanks is complete.**
- **Preliminary designs have been completed for all major components including the drift tubes, post couplers, slug tuners, endwalls, iris waveguide, and tank sections.**
- **Preliminary structural and thermal analysis calculations are complete.**
- **Layouts of the intertank spaces between tanks and the associated packaging of all required diagnostic components are in progress. This includes wires scanners, Faraday cups, Toriods, and energy degraders.**
- **The DTL aluminum cold model assembly and initial alignment is finished. Tuning and field measurements is continuing.**
- **MEBT to DTL interface control drawing (155Y504100) is in progress.**
- **The DTL system design criteria document (SNS-104020000-DC0001-R00) is in progress.**

Tank 1 in Front-End Building



View looking downstream typical for tanks 1 and 2

DTL Tunnel Cross Section

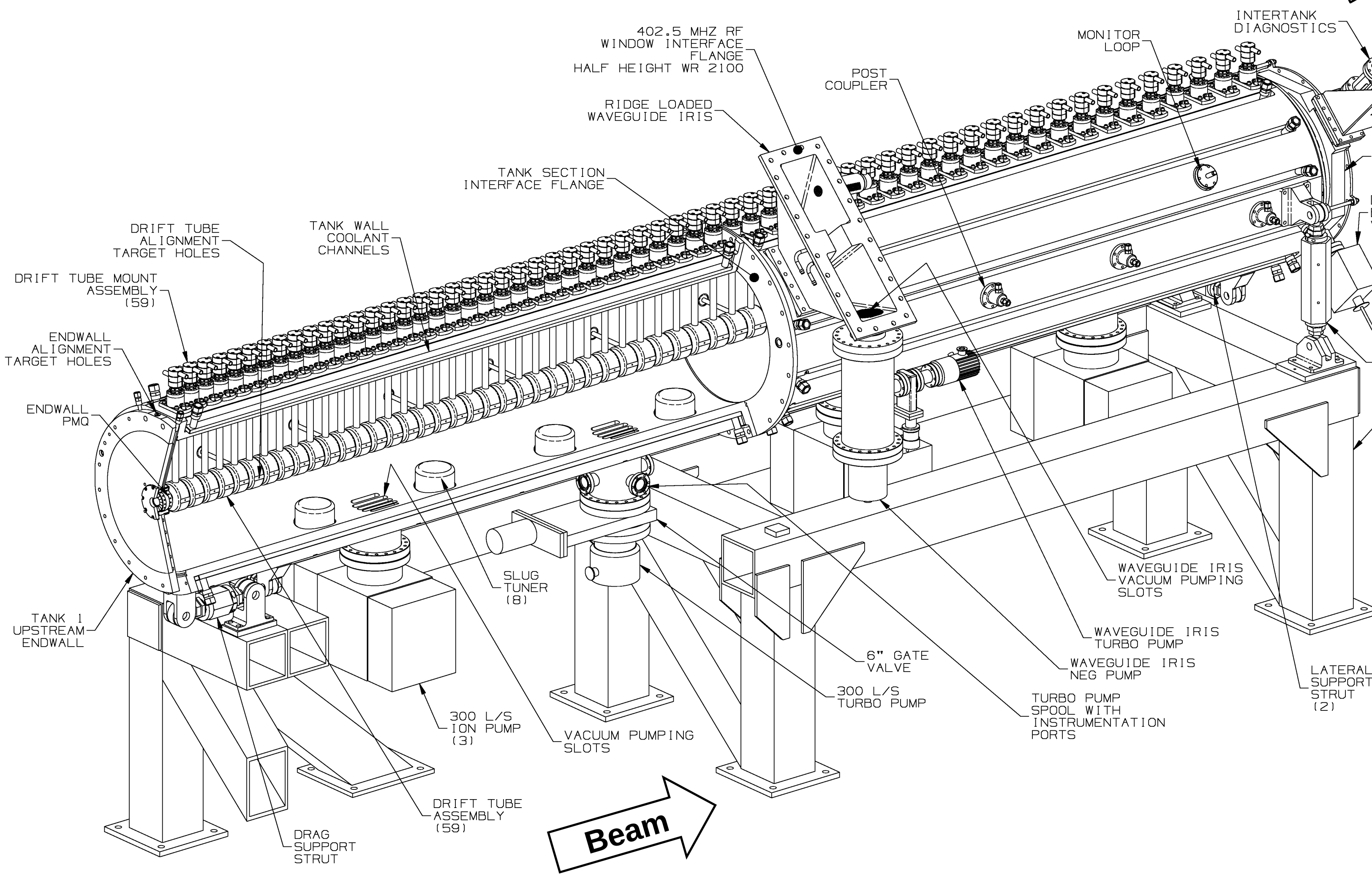


View looking downstream
typical for tanks 3 thru 6

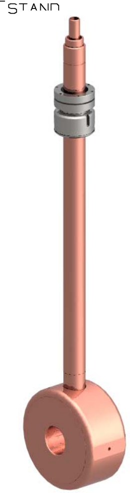
DTL Tank Configuration

Tank #	Exit Energy (MeV)	Total Length (m)	Drift Tubes	Tank Sections	Weight (lbs)
1	7.5	4.15	59	2	10600
2	22.8	6.06	47	3	14400
3	39.8	6.32	33	3	13400
4	56.6	6.41	27	3	13200
5	72.5	6.30	23	3	13600
6	86.8	6.34	21	3	13600

DTL Tank 1 Assembly



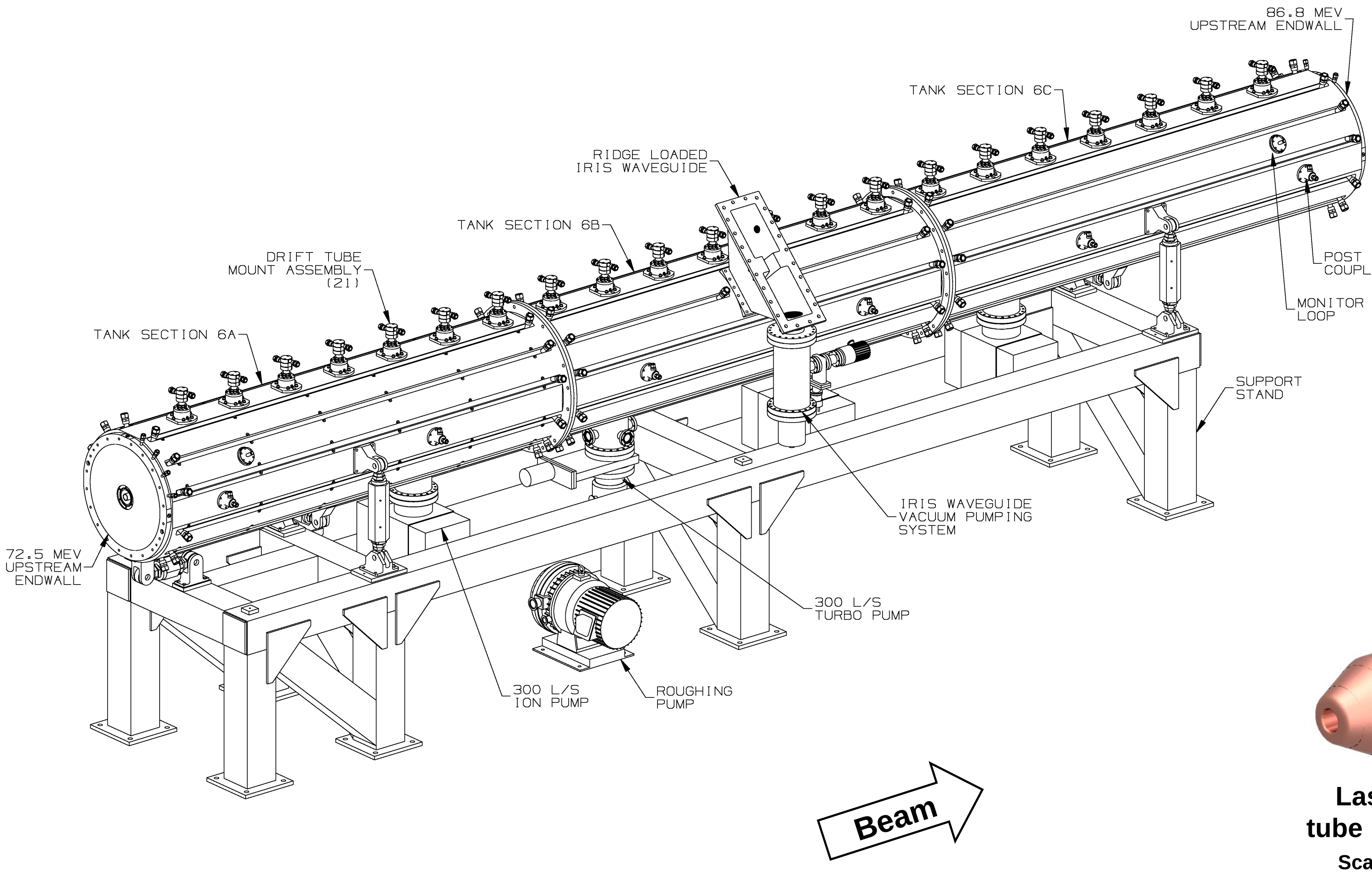
Cutaway View

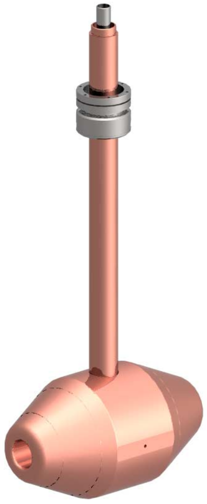


First drift tube in tank 1

Scale ~ 3/1

DTL Tank 6 Assembly

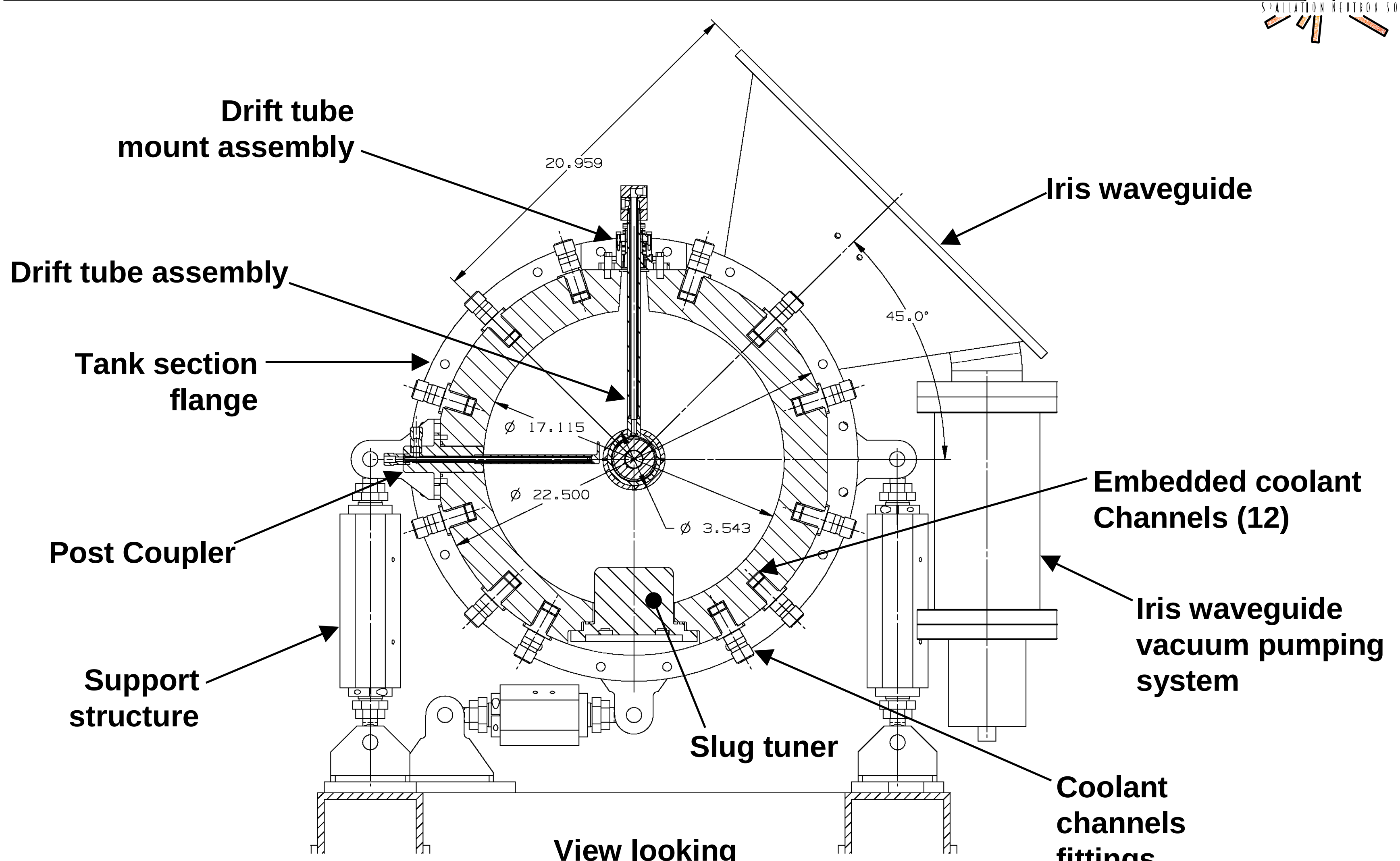




Last drift tube in tank 6

Scale ~ 3/1

Cross Section Thru DTL Tank



View looking
Downstream

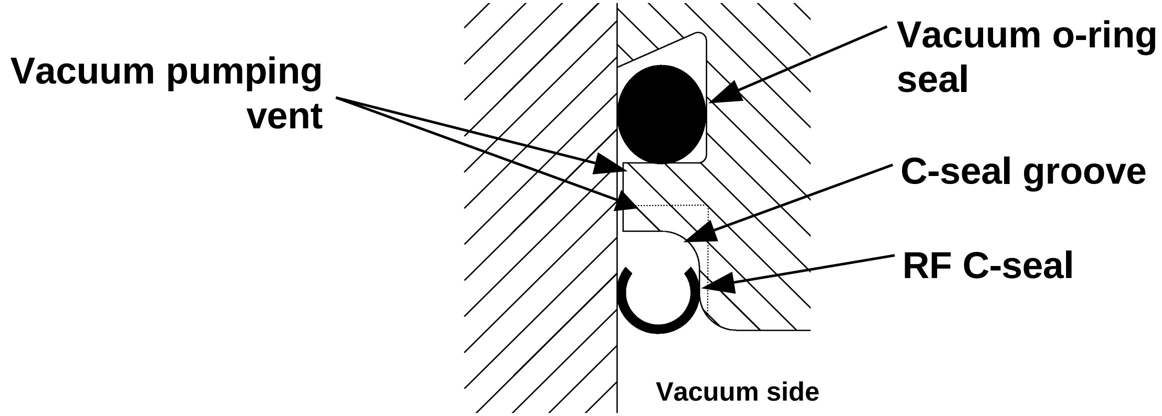
Vacuum Seal Design

- **Resistance to radiation damage is acceptable for Viton o-rings.**
  - Viton Cumulative dose rate limit = 1×10^7 Rads (ref: CERN report ,1982,"Compilation of radiation damage test data".)
  - Calculated total cumulative dose for SNS at 80 Mev = 2.16×10^6 Rads for 30 years (this assumes a particle beam loss of 1 watt/meter and a prompt radiation dose rate =10 Rad/hr at 80 MeV)
- **Permeability rate of Viton o-rings is acceptable for the design pressure.**
  - Total o-ring permeability rate = 5.4×10^{-6} Torr-L/sec
  - Design pressure at drift tube bore = 9.2×10^{-8} Torr (avg.) for N_2, 6.5×10^{-7} Torr (avg.) for H_2

    See "SNS Drift Tube Linac Vacuum System Preliminary Design Report – II, SNS-104020300-DA0001-R01"
- **Viton o-rings are lower cost than metallic vacuum seals.**
  - Metal vacuum seals (i.e. spring energized seals) \$200 to \$500 each
  - Metal vacuum seals are not reusable as vacuum seals
- **Elastomer o-ring seals don't require a robust flange design. Seal compression load is low.**
  - Viton o-rings compression load ~ 10 - 15 lb/in
  - Spring energized seals require robust flange designs, typical compression loads ~ 1000 lb/in

RF Seal Design

- Silver plated Inconel C-seals are used at the Endwalls, Drift tube mount base, tank mating sections, slug tuners, iris waveguide, and vacuum pump spools.
- Multi-contact bands are used in the drift tube mounts and Post couplers.
- RF seal grooves are vented to vacuum seal grooves to prevent virtual leaks.
- RF C-seal compression load ranges from 200 lb/in to 300 lb/in.



Typical RF and vacuum seal groove design

General Fabrication/Procurement Plan

- **Drawings and/or electronic files will be produced for the hardware fabrication.**
  - Tank sections and drift tube body parts will use CAD models for fabrication, i.e. IGES, STEP, or Unigraphics part files. This vastly reduces the amount of detailed drawings required for fabrication.
  - CAD model to fabrication process has been done with the cold model parts with success.
  - Specification drawings are still required, i.e. tolerances, surface finishes, general drawing notes etc…
- **Manufacturing contracts will be placed based on competitive bid to one or more qualified vendors on a firm fixed price basis.**
- **Multiple procurements will be placed.**

Procurement status:

- **PMQ order has been placed.**
- **Procurement for the DTL tank section forgings has started.**

SNS Drift Tube Linear Accelerator
Preliminary Design Review
September 26 & 27, 2000

Drift Tube Assemblies

Overview

Raymond Valicenti

Drift Tube Parameters and Features

- **210 Drift Tube Assemblies**
  - Tank 1 & 2 uses drift tubes with .75” & 1.00” diameter stems
  - Tank 3 - 6 uses drift tubes with 1.25” diameter stems
- **All drift tubes have bore diameters = 2.50 cm**
- **Drift Tube Body Diameters**
  - 9.00 cm Tank 1 & 2
  - 11.00 cm Tank 3 – 6
- **Drift tube component material**
  - Bodies, end caps, inner cooling sleeves & bore tubes - OFHC copper C10100 ASTM F68 Class 2 or better
  - All stem tubes, flow diverters, bellows, mounts and hardware – 304L stainless steel ASTM A269, ASTM A240 and ASTM A276
- **140 Permanent Magnet Quadrupoles (PMQ) drift tubes provide transverse beam focusing**
  - Focusing lattice = FF0DD (every third drift tube does not contain a PMQ)
  - All drift tubes use one size and strength of PMQs
  - Slotted bore tube allows PMQ and drift tube inner body to be exposed to hard vacuum – simplifies the Electron Beam welding with a PMQ in the drift tube body
  - Magnetic center located to alignment target flats on drift tube body within .001” using taut wire apparatus

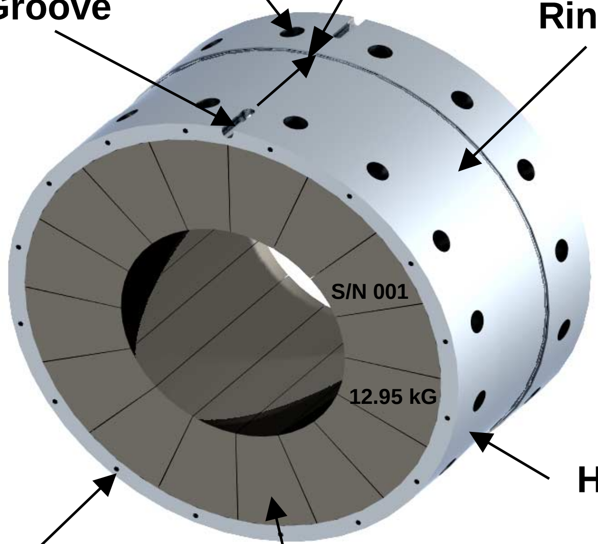
Drift Tube Parameters and Features (con't)

- **36 empty drift tubes**
  - Slotted bore tube allows drift tube inner body to be exposed to hard vacuum
  - Geometric center located to alignment target flats on drift tube body within .001" using coordinate measuring machine(CMM)
- **24 drift tubes with Electro-Magnet Dipoles (EMD)**
  - 4 per tank, 2 vertical & 2 horizontal, for transverse beam steering
  - Sealed bore tube – EMD and drift tube inner body not exposed to hard vacuum
  - Geometric center located to alignment target flats on drift tube body within .001" using a CMM
- **10 drift tubes with Beam Position Monitors (BPM)**
  - 2 per tank in tanks 2 - 6
  - Sealed bore tube – BPM and drift tube inner body not exposed to hard vacuum
  - Geometric center located to alignment target flats on drift tube body within .001" using a CMM

Drift Tube Parameters and Features (con't)

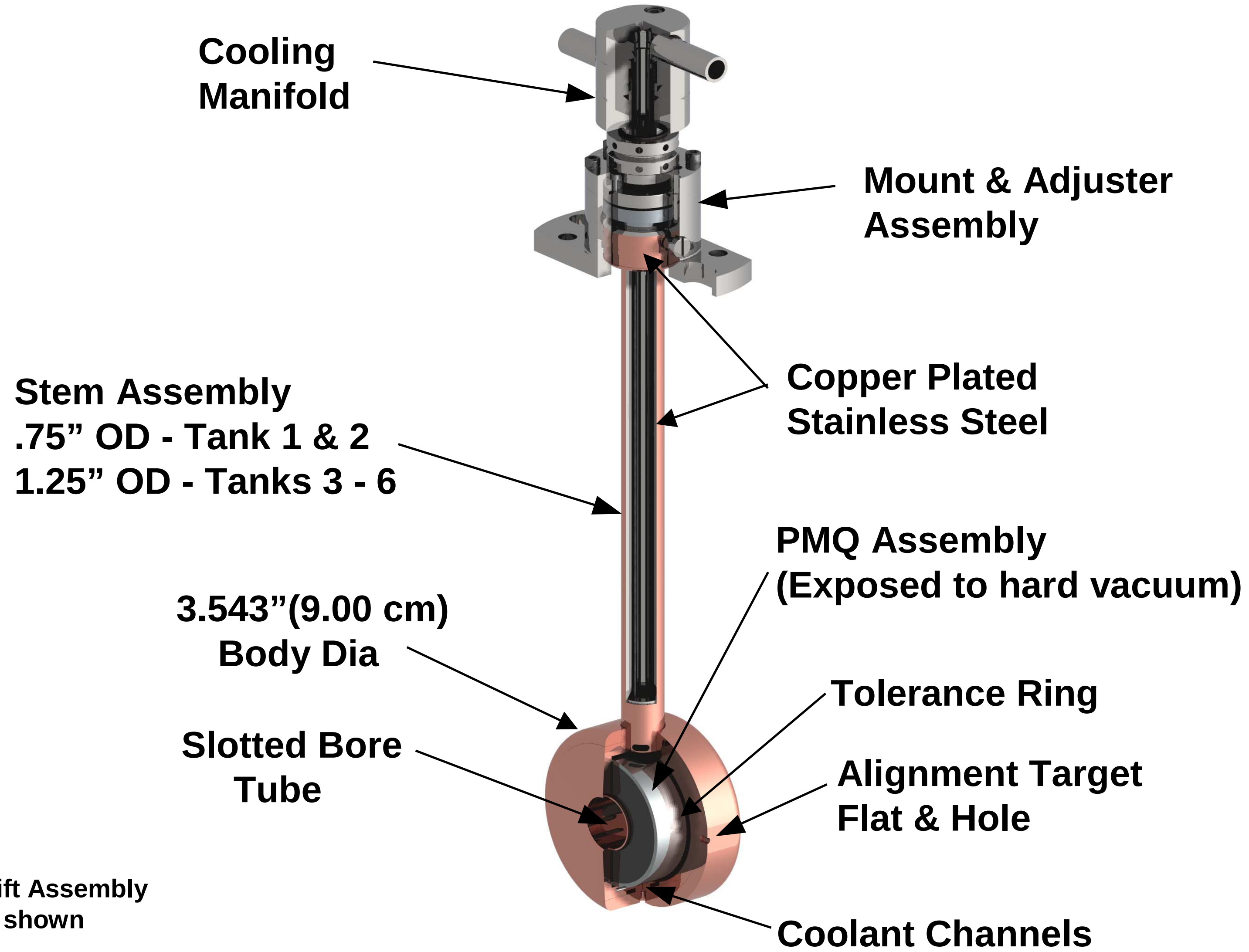
- **All 210 drift tubes use the same mount and adjuster scheme**
- **Coolant channels and tubes provide counterflow stem and drift tube body cooling**
  - Drift tube operating temperature ~ 80^0F
- **DTL vacuum system provides the necessary base pressure and capacity to handle the added gas load of 176 slotted bore tube drift tubes**
- **All drift tube mounts use metal vacuum seals**
  - Silver plated inconel C-seals
- **RF Seals**
  - Silver plated inconel C-seal for mount to DTL tank interface
  - Gold plated multi-contact bands for drift tube stem collar to mount flange

Permanent Magnet Quadrupole (PMQ)



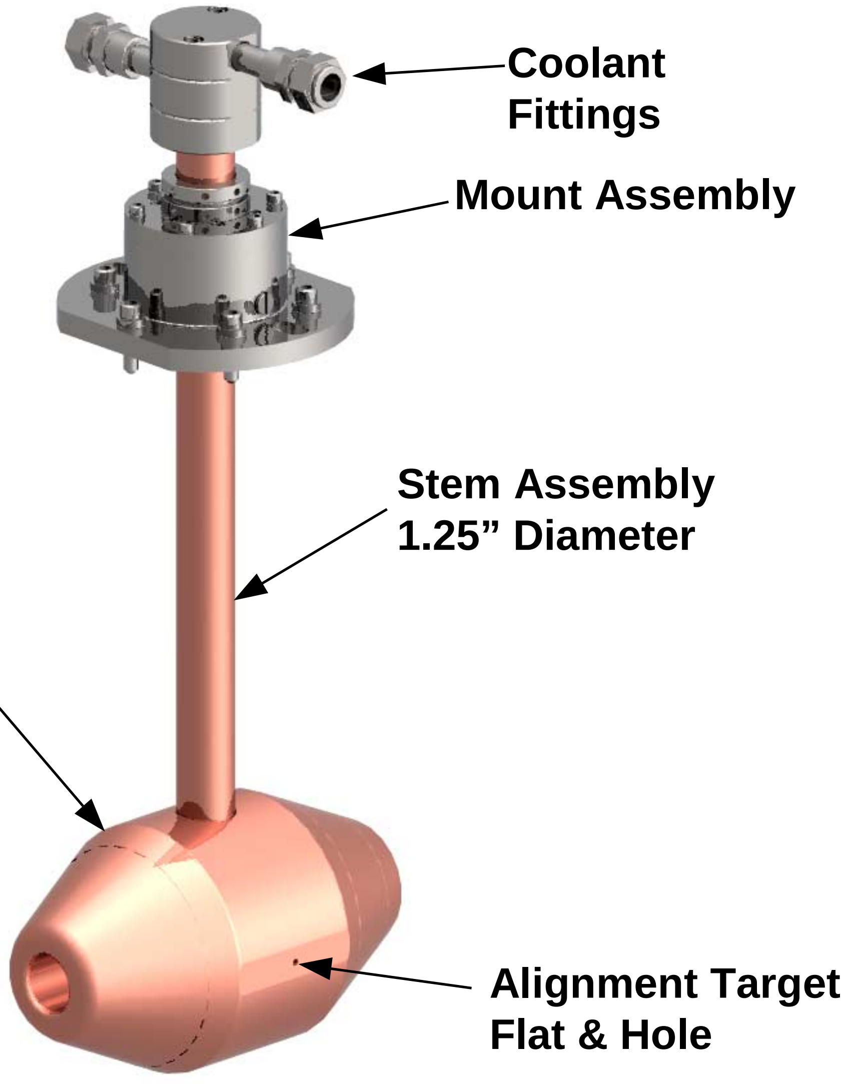
- **Single PMQ design and strength for all DTs**
  - Magnet strength = 12.95 kG
  - Magnet gradient = 3.70 kG/cm
  - Length = 3.50 cm
- **Samarium Cobalt 217 (Sm_2Co_{17}) Magnet Material**
  - Brand & class of PM material selected to minimize field strength loss due to neutron fluence -Vacomax 225 HR
- **Design housing for exposure to hard vacuum (10^{-7} Torr)**
  - Use open design
  - Use venting holes to relieve set screw threads
  - Vacuum clean & bake
  - Max outgassing rate =1.3 x 10^{-7} Torr Liter/sec
- **Housing Material = high strength Aluminum 7075-T6**
  - Minimizes housing distortions due to set screw load on pole pieces
- **Design housing to allow for fool proof installation into drift tubes - no mistaking FO or DO conventions**

PMQ Type Drift Tube Assembly



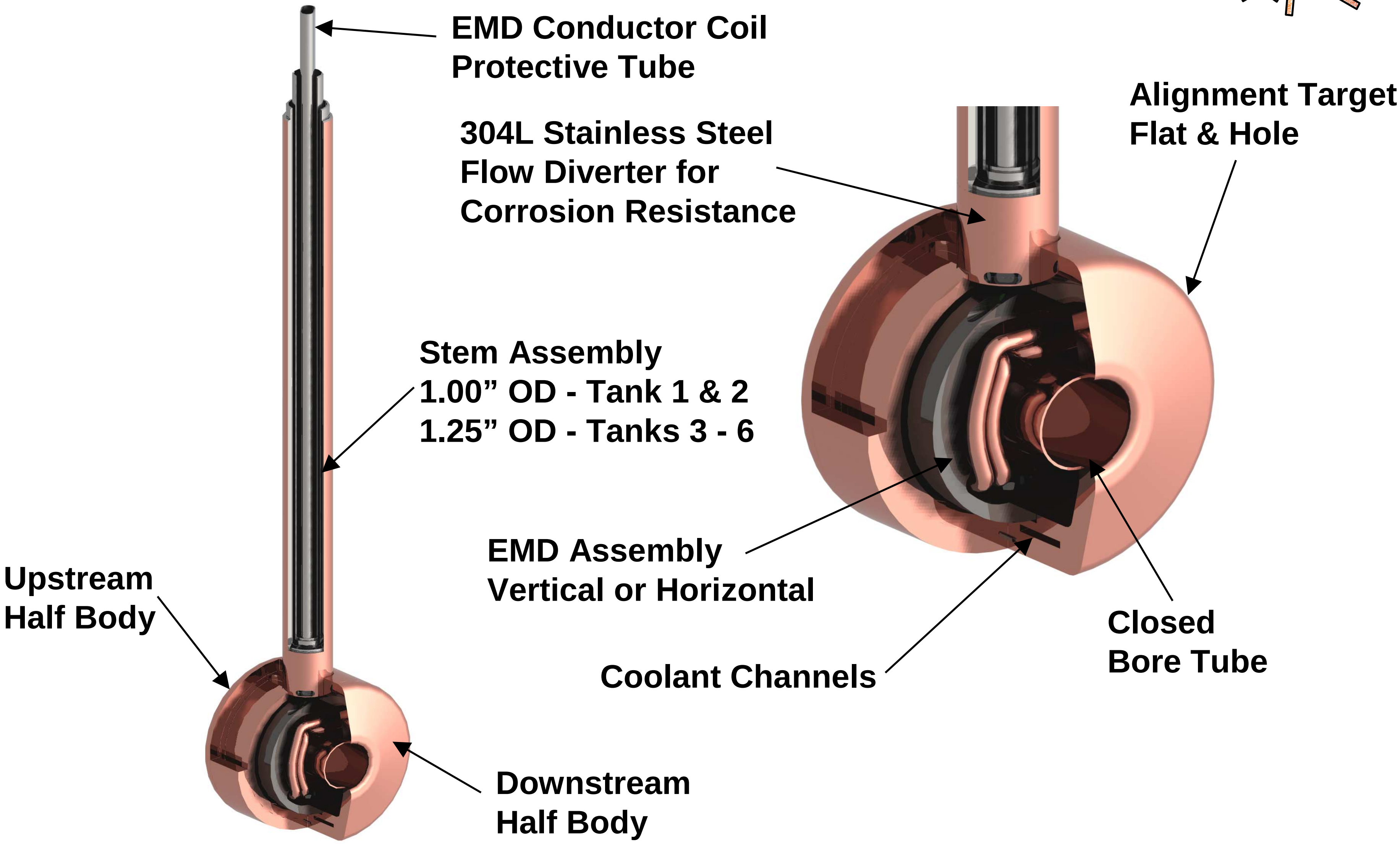
Drift Assembly
#1 shown

High Energy Drift Tube Assembly

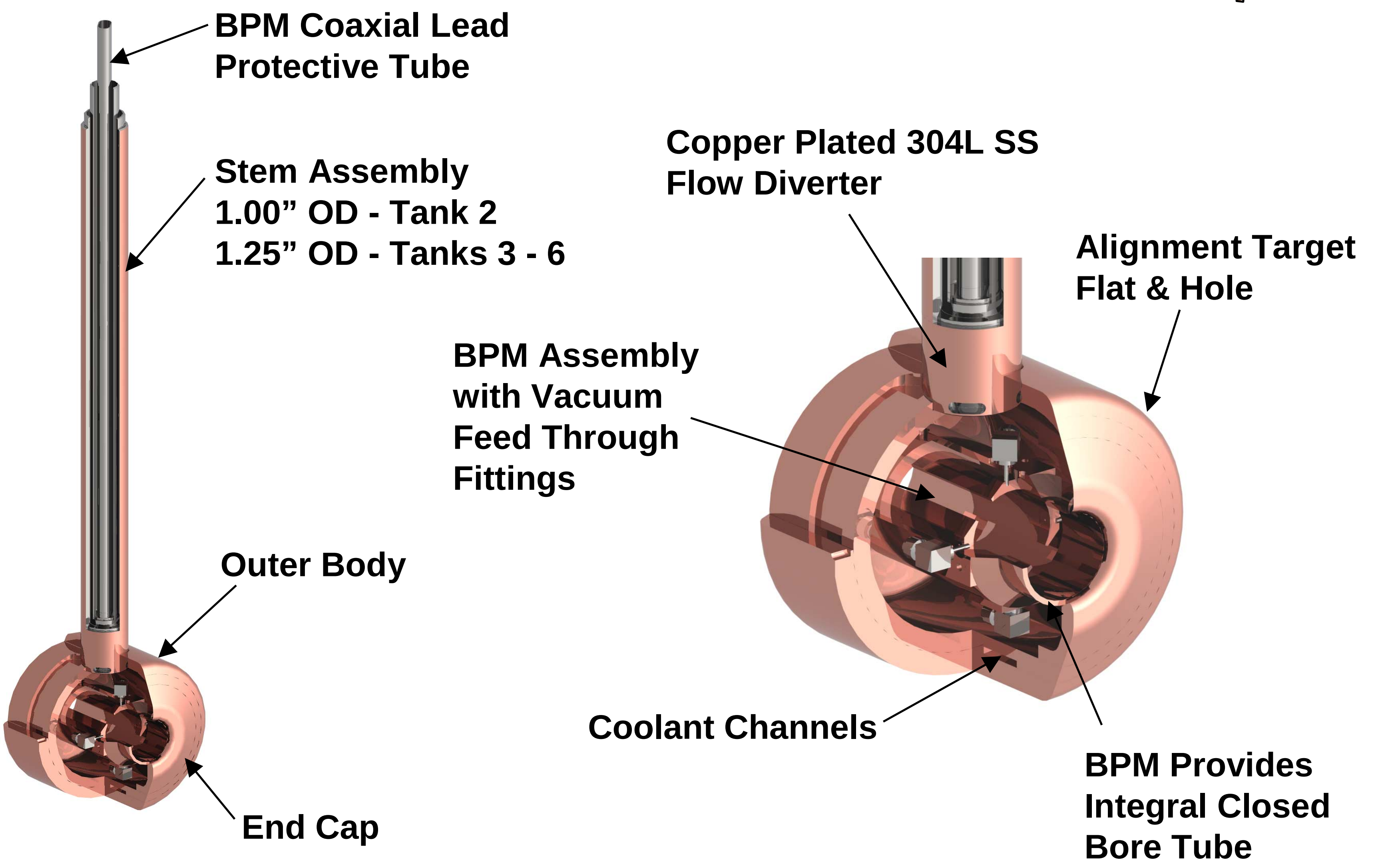


Drift Tube – Tank 6

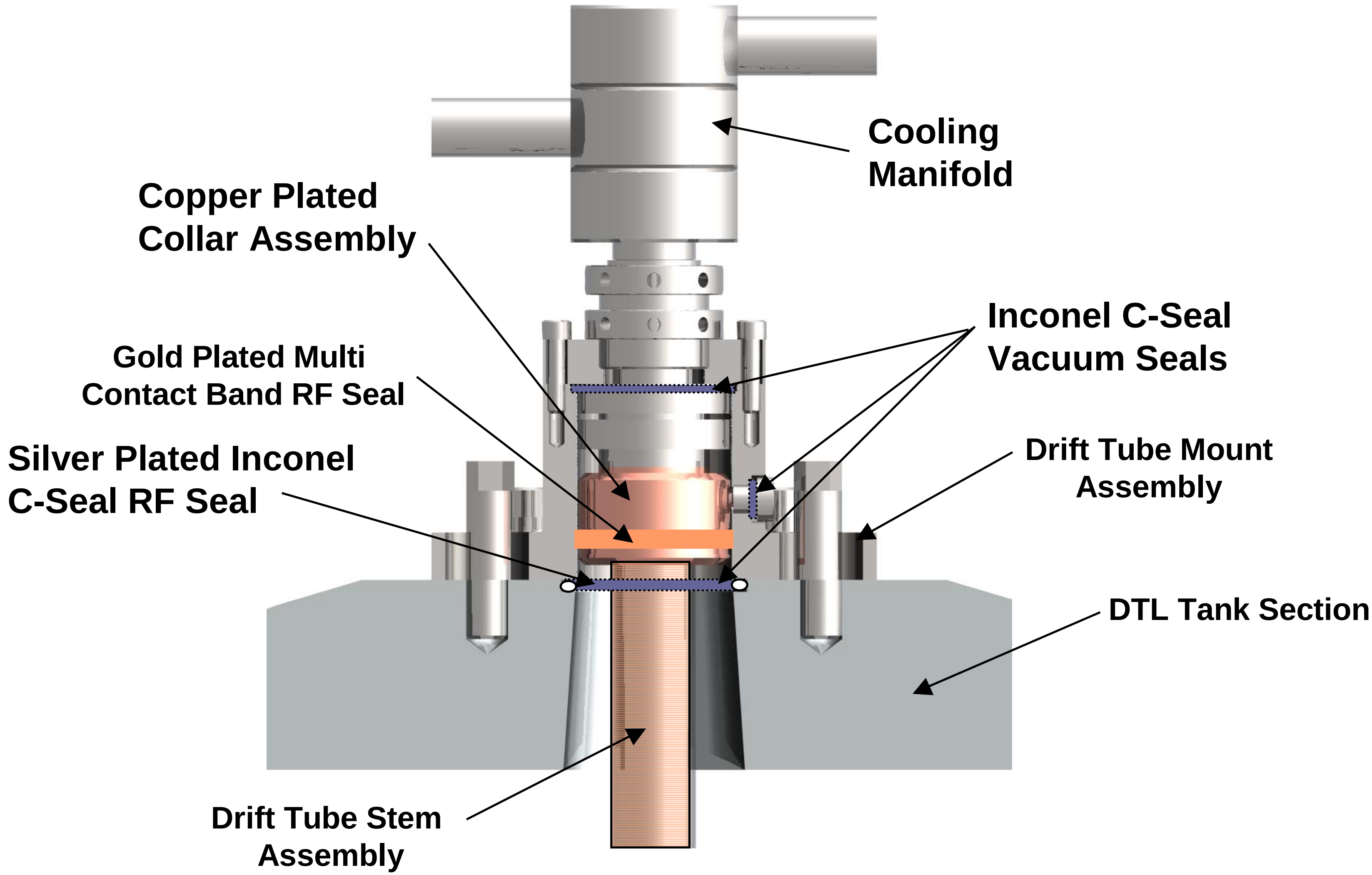
EMD Type Drift Tube Assembly



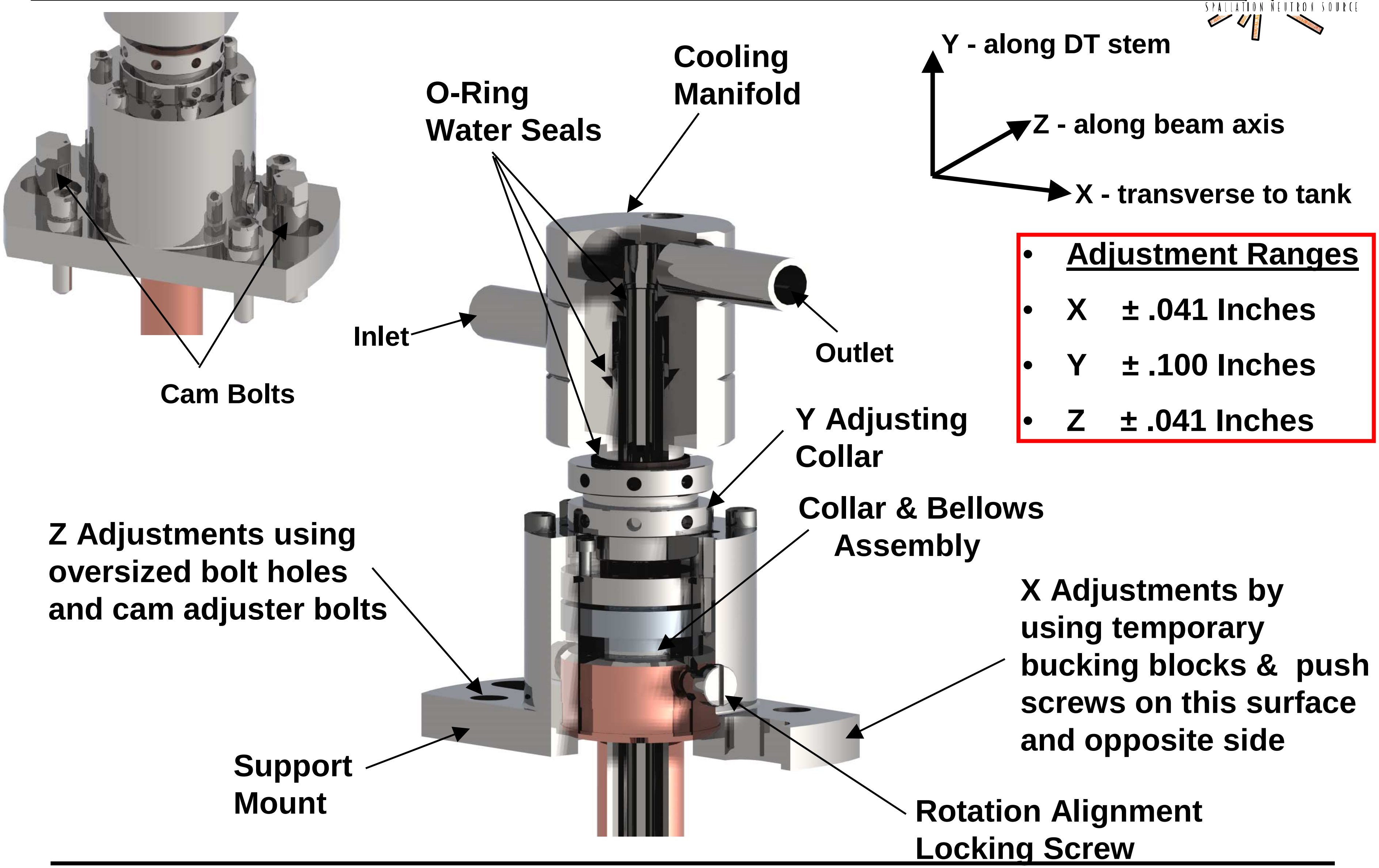
BPM Type Drift Tube Assembly



Drift Tube Vacuum & RF Seals



Typical Drift Tube Mount and Adjusters



- <u>Adjustment Ranges</u>
- X ± .041 Inches
- Y ± .100 Inches
- Z ± .041 Inches

SNS Drift Tube Linear Accelerator
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Prototype Fabrications

& Pre Production

Qualification Tests

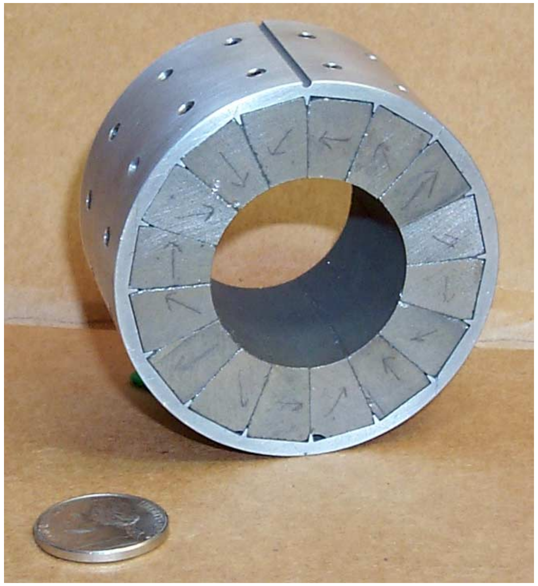
Raymond Valicenti

Drift Tube Prototype Hardware

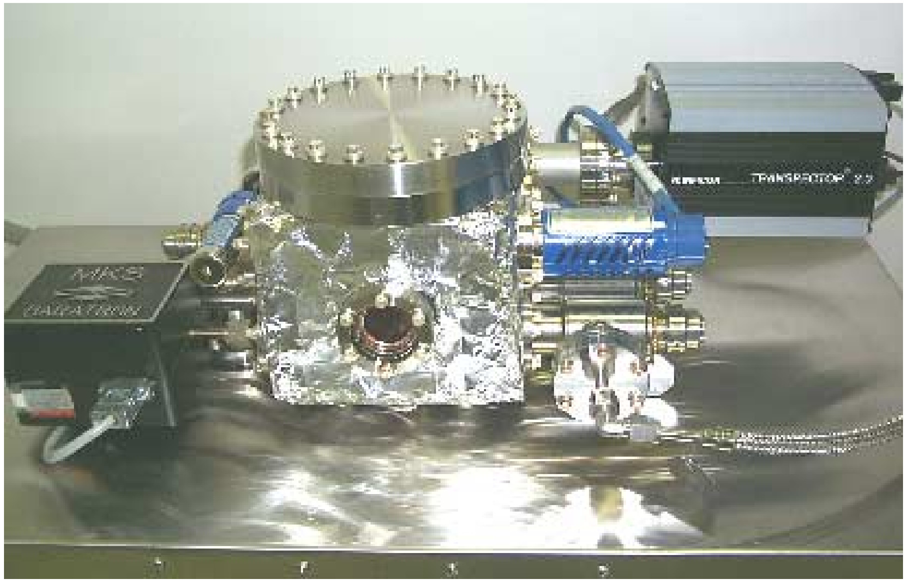
- **Procured 5 prototype PMQs having 3 different sizes and strengths.**
  - PMQs at the time of order were based on the 20 MeV DTL baseline
  - All PMQs were designed for hard vacuum exposure
  - PMQs would be used for outgassing measurements for sizing the vacuum system
  - PMQs would allow for vendor qualification for production fabrication
  - PMQs would provide for Electron Beam welding process development
  - PMQs would be used inside 3 prototype drift tube assemblies
- **Procured 6 drift tube flow test models**
- **Procured drift tube dynamic mass model**
- **Procuring 3 prototype PMQ drift tubes**
  - Qualifying 2 fabricators in all detailed steps and processes required to produce drift tubes
    - » Develop & qualify deep full penetration EB welding processes
    - » Develop & qualify EW welding in vicinity of PMQ's magnetic field
    - » Develop & qualify brazing processes
    - » Develop & qualify copper plating processes
- **Procuring vacuum vessel, stand and covers for performing prototype drift tube vacuum seal check & outgassing measurements**
- **Procuring 1 - 2 EMD prototype drift tubes – requires complicated brazed assembly**
- **Procuring 1 BPM prototype drift tube – 75% equivalent fabrication to PMQ type drift tube assembly process**

Prototype PMQ Outgassing Measurements

- **Confirmed suitability of PMQ design for hard vacuum use**
- **Obtained outgassing rates for use in vacuum system sizing calculations**
  - PMQ Outgassing Rate = 1.25×10^{-7} Torr-Liter/sec
  - Pump down time to obtain minimum outgassing rate = 124 Hrs
- **Established maximum outgassing rate specification for production PMQs**
- **Established vacuum cleaning and baking procedures to be used on the production PMQs**

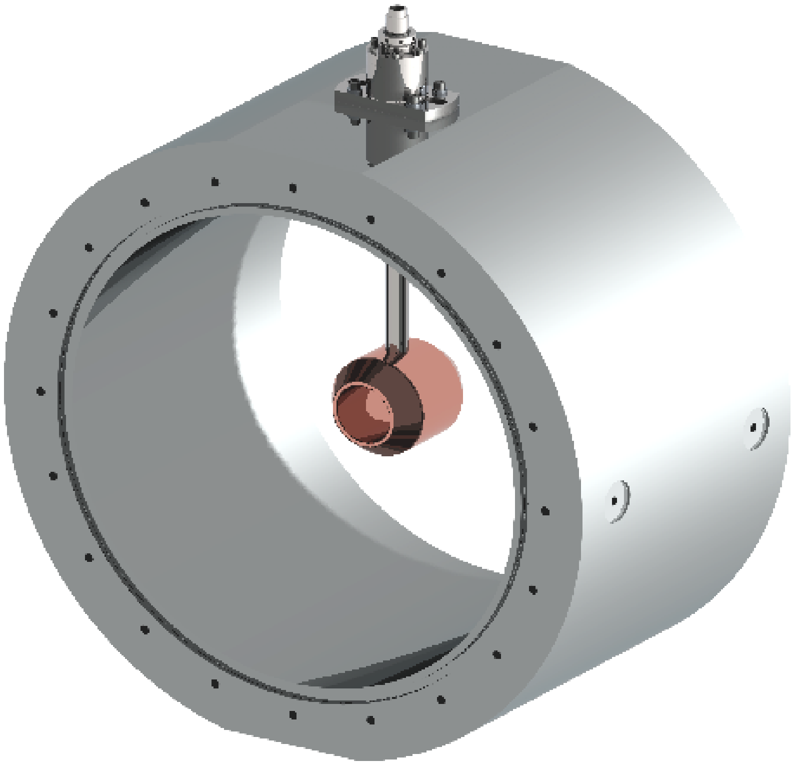


Prototype PMQ Assembly (1 of 5)



Outgassing Measurement Test Stand

Mass Model Dynamic Test Setup



- **Evaluate dynamic response of worst case drift tube**
  - .75” Dia stem
  - Drift tube mass simulates DT # 47 in tank 2 with a PMQ installed
- **Evaluate stiffness and damping of mount/adjuster scheme**
  - Effects on stiffness due to types and fits of gold plated multi contact band RF Seals
- **Evaluate suitability of shipping DTL tank assembled with drift tubes from LANL to Oak Ridge**
- **Evaluate effect on drift tube stem and mount resulting from transporting DTL assembly down extreme inclined ramps (grade or tunnel access)**

Prototype DT Vacuum Check & Outgassing Measurement

- **Evaluate vacuum seal function, type and integrity**
- **Perform outgassing measurement of 3 prototype drift tube assemblies**
- **Verify alignment stability of prototype drift tubes and mounts under vacuum load**
  - Utilize laser tracker setup - looking at targets through 6" Dia viewport
- **Evaluate prototype drift tube fabricators for vacuum cleanliness and handling procedures - lowest outgassing rate**
- **Practice aligning drift tubes using laser tracker**

Pre Production PMQ Outgassing Measurement

Pre Production PMQ Article

- **Evaluate and modify the PMQ's housing design as required to meet the maximum specified outgassing rate prior to committing to the fabrication of 160 PMQs**
  - The PMQ vendor, as part of the procurement contract will provide LANL with a pre production outgassing test article that will represent the proposed PMQ housing in all its detail, but fitted with non magnetized pole pieces
  - Test article will be cleaned and baked per production specifications
- **Evaluate the vacuum cleaning, baking and handling procedures to be used on the production PMQs**

SNS Drift Tube Linear Accelerator
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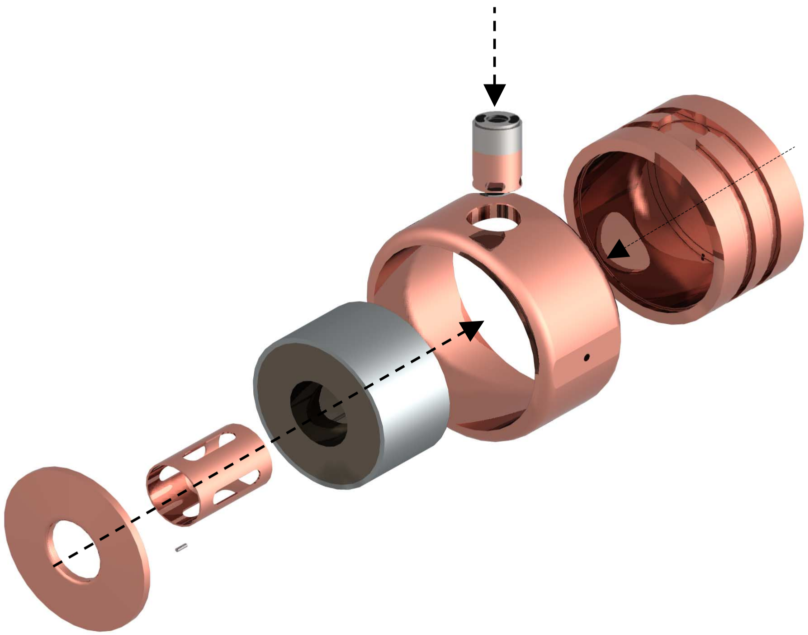
Drift Tube Assemblies

Manufacturing Steps

Raymond Valicenti

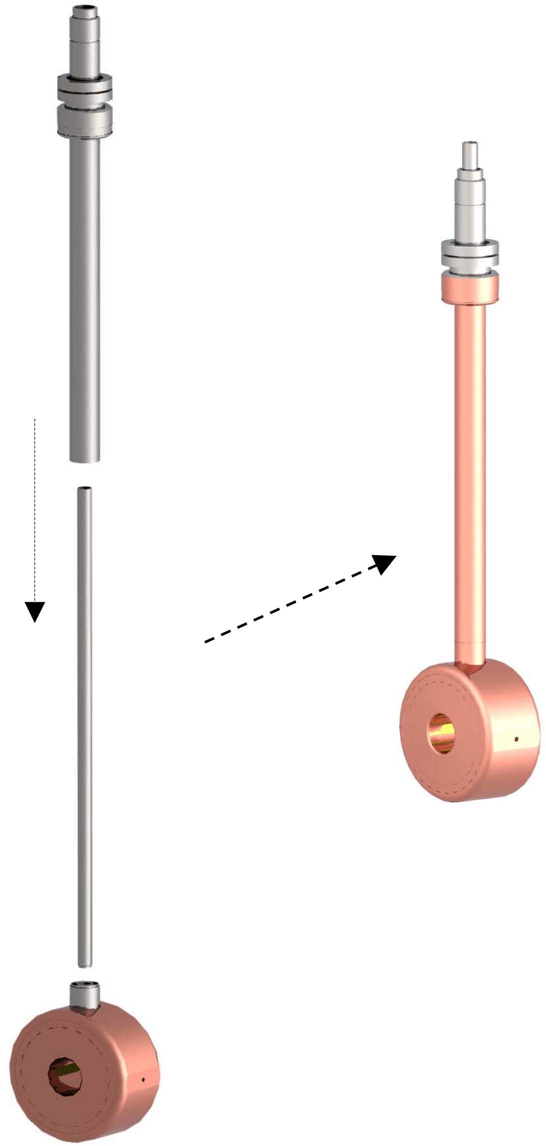
PMQ Type Drift Tube Assembly Steps

- 140 Drift Tubes with PMQs
- 36 Drift Tubes without PMQs
- .75“ OD DT stems in tank 1 & 2
- 1.25“ OD DT stems in tank 3 - 6



1) Rough machine inner sleeve & outer body.
2) Perform deep continuous Electron Beam (EB) coolant channel welds.
3) Final machine OD & bore diverter tube hole.
4) Final machine/EDM stainless steel diverter piece.
5) Copper Plate diverter tube to above braze joint height.
6) Oven braze diverter tube to drift tube body – using a single low temperature (<1500° F) braze cycle.
7) Perform helium leak check & acceptance.
8) Final machine drift tube/braze assembly inner body features.
9) Install inner stainless steel coolant tube & orbital weld to diverter tube.
10) Install outer stainless steel stem tube/bellows assembly & orbital weld to diverter tube.
11) Perform helium leak check & acceptance.
12) Verify PMQ’s serial # to the drift tube’s serial # and magnet installation direction for correct polarity(FO or DO) with polarity meter – install in alignment fixture.

PMQ Type Drift Tube Assembly Steps (con't)



13) Using the PMQ magnetic axis angle alignment and PMQ installation jig set up - install the PMQ and tolerance ring and align the magnetic axis to the stem reference datums within 0.35°.

14) Install anti rotation pin in PMQ groove, install bore tube, align pin with hole in cap, and freeze fit end cap to drift body.

15) Electron beam weld bore tube and end cap to body.

16) Perform magnet field map of completed drift tube/PMQ weld assembly at LANL to verify magnet integrity (this step needs to be performed on the shortest drift tubes with PMQs only).

17) Final profile machine drift tube assembly.

18) Final 100 % dimensional inspection and stem to drift tube body alignment verification.

19) Copper plate outer stem below bellows up to diverter tube's copper plating.

20) Inspect and verify copper plate thickness and integrity.

21) Nylon bag with dry nitrogen back fill and ship to LANL.

PMQ Type Drift Tube Assembly Steps (con't)

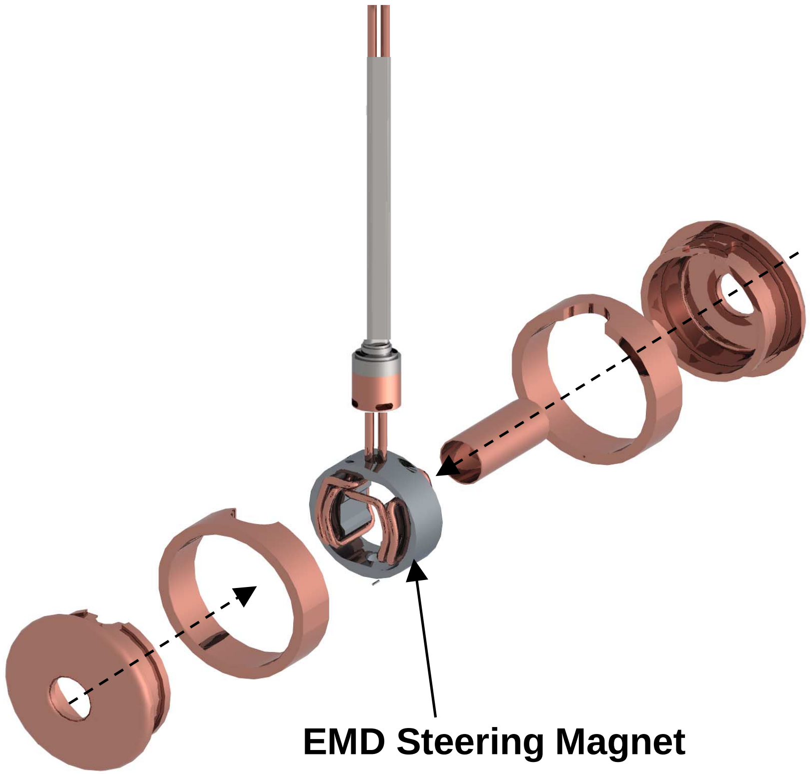
22) **Final magnet map and verify.**

23) **Correlate magnet center X & Y component to drift tube alignment target flats to .001" using the taut wire apparatus. Generate a laser alignment offset table database.**

24) **Nylon bag with dry nitrogen back fill, box and store until final assembly.**

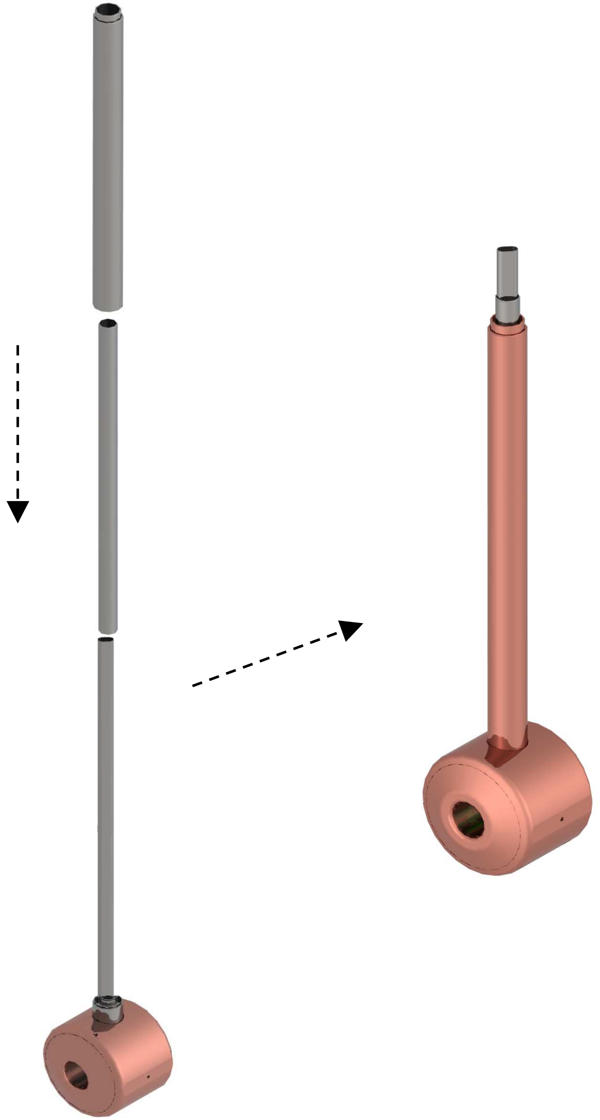
EMD (Steering Magnet) Type Drift Tube Assembly Steps

- 24 Drift Tubes with EMDs
- 2 Horizontal Steering DTs per Tank
- 2 Vertical Steering DTs per Tank
- 1.00“ OD DT stems in tank 1 & 2
- 1.25“ OD DT stems in tank 3 - 6



1) Rough machine upstream and downstream integral inner sleeve/end caps and outer body halves.
2) Perform deep continuous Electron Beam (EB) coolant channel welds.
3) Final machine OD, diverter tube bore and internal features.
4) Final machine/EDM stainless steel diverter piece.
5) Copper Plate diverter tube to above braze joint height.
6) Install the coil conductor’s protective stainless steel sleeve and orbital weld to the diverter tube.
7) Install the 2 body halves around the potted EMD and feed the conductor leads through the diverter tube.
8) Oven braze the 2 drift tube body halves,diverter tube, potted EMD and bore tube using a single braze cycle.
9) Perform a helium leak check & acceptance.
10) Perform a magnet field map of the EMD drift tube braze subassembly - verify the integrity of the EMD.
11) Install the inner stainless steel coolant tube & orbital weld to diverter tube.

EMD (Steering Magnet) Type Drift Tube Assembly Steps (con't)



13) Install the outer stainless steel stem tube/bellows assembly & orbital weld to diverter tube.

14) Perform helium leak check & acceptance.

15) Final profile machine the EMD drift tube/stem assembly.

16) Final 100 % dimensional inspection and stem to drift tube body alignment verification.

17) Copper plate outer stem below bellows and up to diverter tube.

18) Inspect and verify copper plate thickness and integrity.

19) Nylon bag with dry nitrogen back fill and ship to LANL.

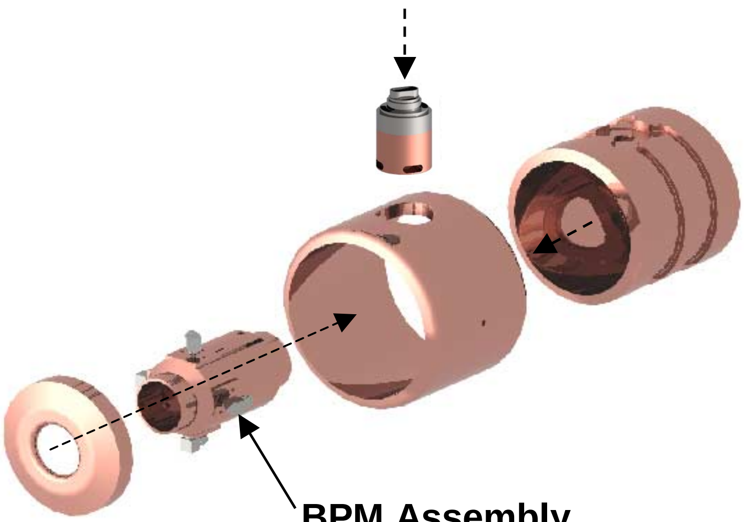
20) Final magnet map and verify.

21) Locate geometric center X & Y component to drift tube alignment target flats using a CMM – create laser alignment offset table database.

22) Nylon bag with dry nitrogen back fill, box and store until final assembly.

BPM (Beam Position Monitor) Type Drift Tube Assembly Steps

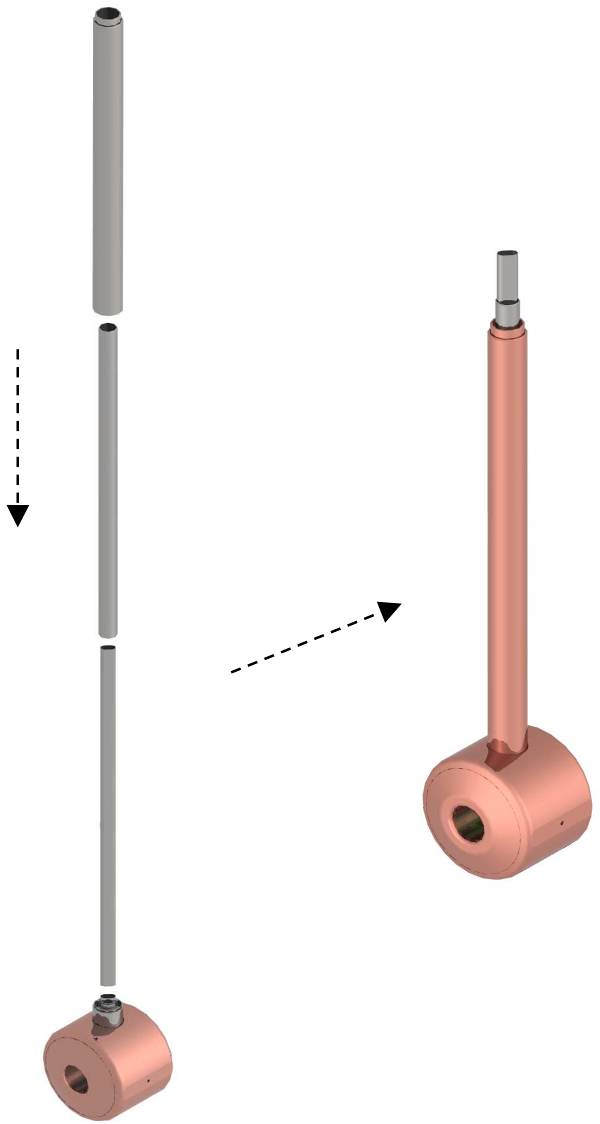
- 10 Drift Tubes with BPMs
- 2 per Tank in Tank 2- 6
- 1.00“ OD DT stems in tank 2
- 1.25“ OD DT stems in tank 3 - 6



BPM Assembly

1) Rough machine inner sleeve & outer body.
2) Perform deep continuous Electron Beam (EB) coolant channel welds.
3) Final machine OD and bore diverter tube hole.
4) Final machine/EDM stainless steel diverter piece.
5) Copper Plate diverter tube to above braze joint height.
6) Oven braze stainless steel diverter tube to drift tube body using single low temperature braze cycle.
7) Perform helium leak check & acceptance.
8) Final machine drift tube inner body features & BPM alignment key grooves.
9) Install the coaxial cable’s stainless steel protective sleeve and orbital weld to diverter tube.
10) Install inner stainless steel coolant tube & orbital weld to diverter tube.
11) Install outer stainless steel stem tube/bellows assembly & orbital weld to diverter tube.
12) Perform helium leak check & acceptance.

BPM (Beam Position Monitor) Type Drift Tube Assembly Steps (con't)



13) Feed the 4 coaxial leads through the stem sleeve & diverter tube and make proper connections to vacuum feed throughs on BPM.

14) Install BPM assembly up to drift body end cap, verify angular clocking with alignment keys and pull excess coaxial cable up through stem tube.

15) Verify electrical integrity of BPM.

16) Freeze fit end cap to drift tube body.

17) Electron beam weld end cap and bore tube ends - produce vacuum tight continuous weld joints.

18) Perform helium leak check & acceptance.

19) Verify vacuum and electrical integrity of BPM.

20) Final profile machine drift tube/stem assembly.

21) Final 100 % dimensional inspection and stem to drift tube body alignment verification.

22) Copper plate outer stem below bellows and up to copper plating on diverter tube.

23) Inspect and verify copper plate thickness and integrity.

BPM (Beam Position Monitor) Type Drift Tube Assembly Steps (con't)

24) Nylon bag with dry nitrogen back fill and ship to LANL.

25) Final BPM signal integrity verification.

26) Locate geometric center X & Y components to drift tube alignment target flats using a CMM – create laser alignment offset table database.

27) Nylon bag with dry nitrogen back fill, box and store until final assembly.

SNS Drift Tube Linear Accelerator
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PMQ and Drift Tube

Procurement Strategies

Raymond Valicenti

PMQ Procurement Strategies

- **Production PMQs**
  - Option A
    - » Specify and manufacture all PMQs with magnet strengths of 12.95 kG ± 0.5 % max
    - » Specify staged delivery – PMQs plus spares for Tank 1 first.
    - » The PMQs can be be used in any drift tube assembly.
    - » High cost - Approx. $4500 for each PMQ assembly.
  - Option B
    - » Specify and manufacture all PMQs with magnet strengths of 12.95 kG ± 2.0 % max
    - » Specify total delivery – 160 PMQs includes 13 spares for all tanks.
    - » The PMQs must be sorted by decreasing strength.
    - » Drift tube # 1 would use the PMQ with greatest strength and so on.
    - » Each drift tube must use a unique PMQ with no mistakes
    - » Low cost - Approx. $2050 for each PMQ assembly.

  - Option B offers the best value for the SNS project
  - A contract for 160 Option B PMQs with a June 4, 2001 delivery has been placed.

Drift Tube Procurement Strategies

- **Production Drift Tubes**
  - Require that the drift tube main contractor manage the entire production contract - the vendor will be responsible for paying any subcontracts and will be liable for their work
    - » Must produce all 3 types of drift tubes – PMQ, EMD and BPM
    - » Can use multiple machine shops
    - » Must use a single qualified Electron Beam welder – for consistent process
    - » Must use a single qualified braze house – for consistent processes, but can use different braze processes for EMD and PMQ/BPM drift tube assemblies
    - » Must use a single qualified leak check vendor – for consistent process
    - » Must use a single qualified copper plating vendor – for consistent process
  - Begin the procurement process November, 2000
    - » Write SOWs and specs for 3 types of drift tube assemblies – PMQ, EMD & BPM
    - » Competitively bid the contract to the 2 main contractors which produced qualified prototype drift tube assemblies
    - » Evaluate bids on cost and schedule – since both vendors have very good capabilities
    - » Select a vendor or multiple vendors
  - A contract for 210 drift tubes needs to be awarded by February, 2001 for delivery of Tank 1 drift tube assemblies by September, 2001
    - » 55 PMQ and empty type drift tube assemblies
    - » 4 EMD type drift tube assemblies

SNS Drift Tube Linear Accelerator
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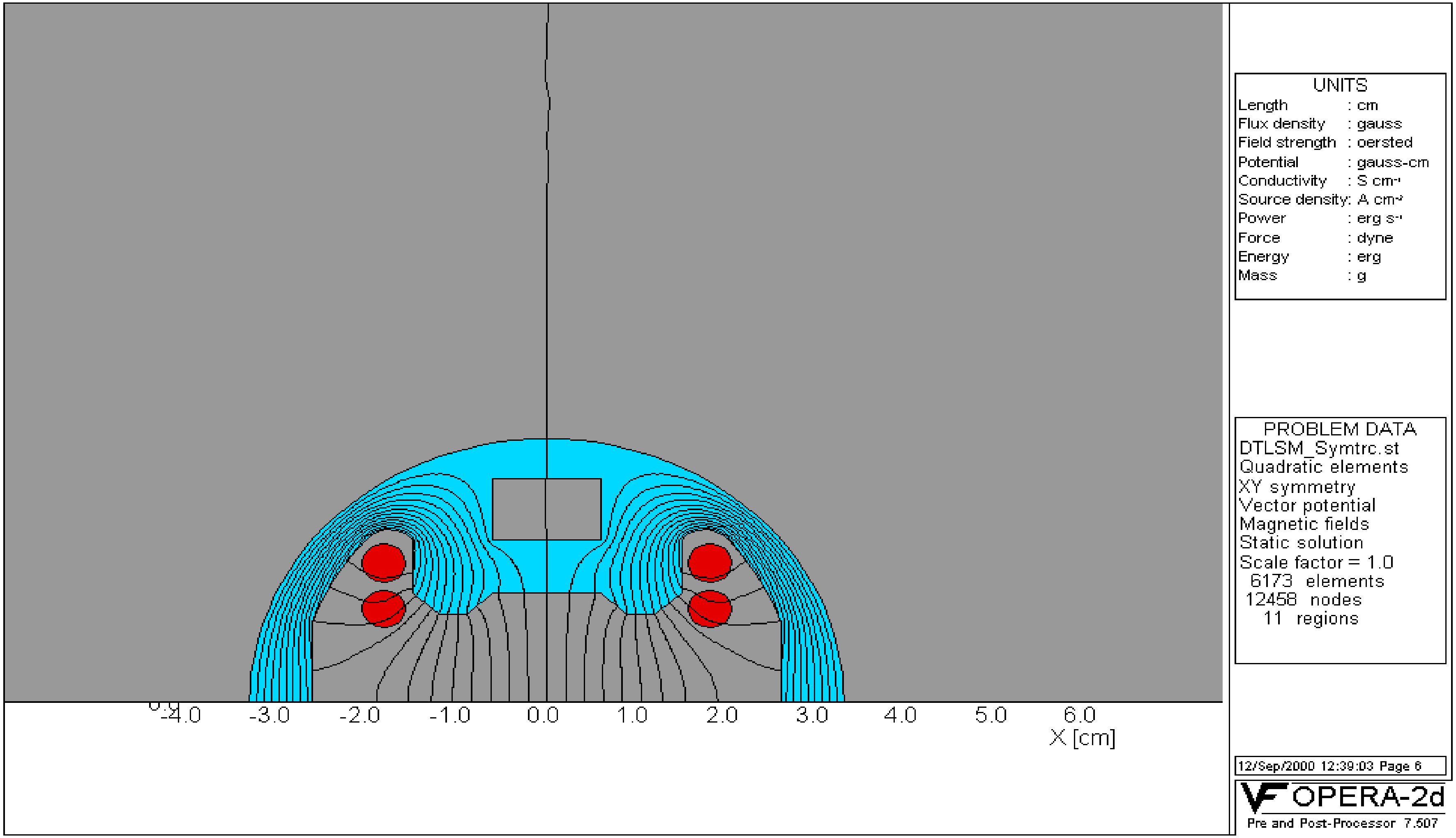
Steering Dipoles

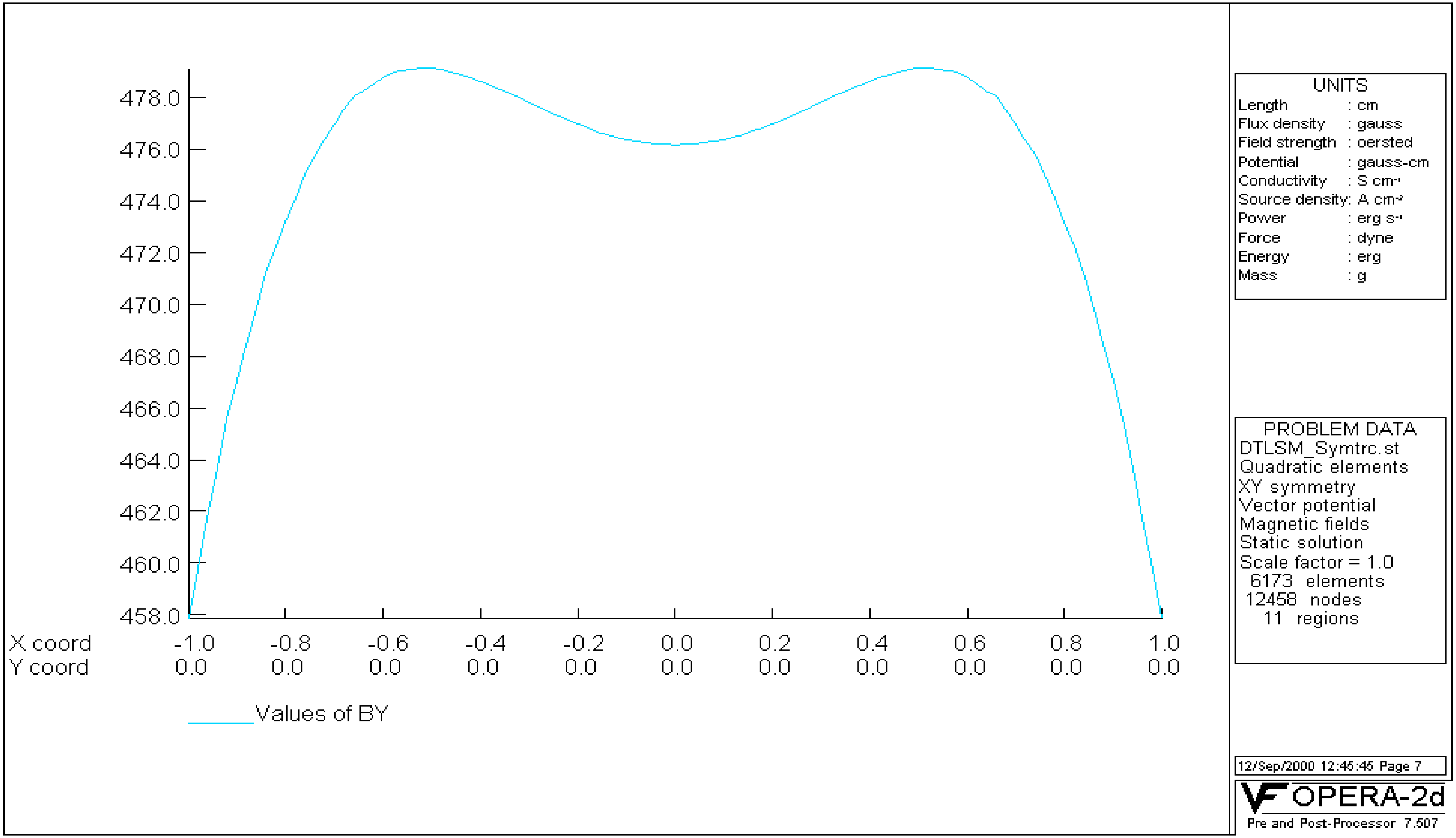
Steering Dipoles

- **Design Requirements**
  - 1600 Gauss-cm BL product
  - Fit within existing Drift Tubes
  - Withstand Braze heat temperatures with no adverse affects
  - Insulation system not hygroscopic
  - Minimum of two horizontal and two vertical magnets/tank

Steering Dipoles



Steering Dipoles



Steering Dipoles

Dipole Data	***User Inputs***	
Steel Length	***2.25***	*cm*
Steel Area	***3.66***	*cm^2*
Gap	***2.80***	*cm*
Turns/Pole	***2***	*Turns*
Turns/Cooling Circuit	***4***	*Turns*
Turn Length	***13.80***	*in*
Flow Velocity	***10.00***	*ft/sec*
Pole Tip Field	***455***	*gauss*
Current	246	amps
BxL	1661	Gauss cm
Amp Turns	492	amp-turns
Total Length/Circuit	55	in
Leff	3.65	cm
Conductor Information		
Type	2	
"3/16 Tube"	0.187	in
Cooling Tube I.D.	0.125	in
Area Cu	0.015	in^2
Water Area	0.012	in^2
D.C. Electrical Calculations		
Total Amp-Turns	984	
Amperes	246	amps
Ohms/circuit	0.003	ohms
Volts	0.71	volts
Power/circuit	175.35	watt
Current density	16400	amps/in^2
Total Power	351	Watt
Cooling Calculations		
Circuit Length	4.60	ft.
Flow	0.38	gpm
Delta-T	3.13	deg f
FrictFact	0.042	
Delta-P	11.79	lb/in^2

Steering Dipoles

Field Calculations

Harmonic analysis of #BR

along line (1.0 ,0.0) to (-1.0 ,0.0)

Curvature = -1.0

Fourier coefficients

Half period analysed, odd terms only

Order	Sine term	Cosine term	Amplitude	Phase
0	0.0	-0.37374094	0.373740940	-180.000000
1	-476.165076	0.747481879	476.1656622	89.91005741
2	0.068844861	-0.74748188	0.750645572	-174.737768
3	-22.1126129	0.747481879	22.12524305	88.06394406
4	-9.2592E-04	-0.74748188	0.747482453	179.9290266
5	38.82087743	0.747481879	38.82807301	-88.8969269
6	-0.01722418	-0.74748188	0.747680301	178.6799702
7	7.703371553	0.747481879	7.739551825	-84.4577647
8	-0.02475969	-0.74748188	0.747891839	178.1028204
9	-7.06756162	0.747481879	7.106979416	83.96270773
10	-0.03392930	-0.74748188	0.748251533	177.4010444
11	0.401242505	0.747481879	0.848365904	-28.2265602
12	0.036909734	-0.74748188	0.748392603	-177.173101
13	0.894371018	0.747481879	1.165602281	-50.1123828
14	0.047106939	-0.74748188	0.748964768	-176.393941
15	-0.29214081	0.747481879	0.802543092	21.34721351

Continue

Return

-4.0

UNITS
Length : cm
Flux density : gauss
Field strength : oersted
Potential : gauss-cm
Conductivity : S cm⁻¹
Source density: A cm⁻²
Power : erg s⁻¹
Force : dyne
Energy : erg
Mass : g

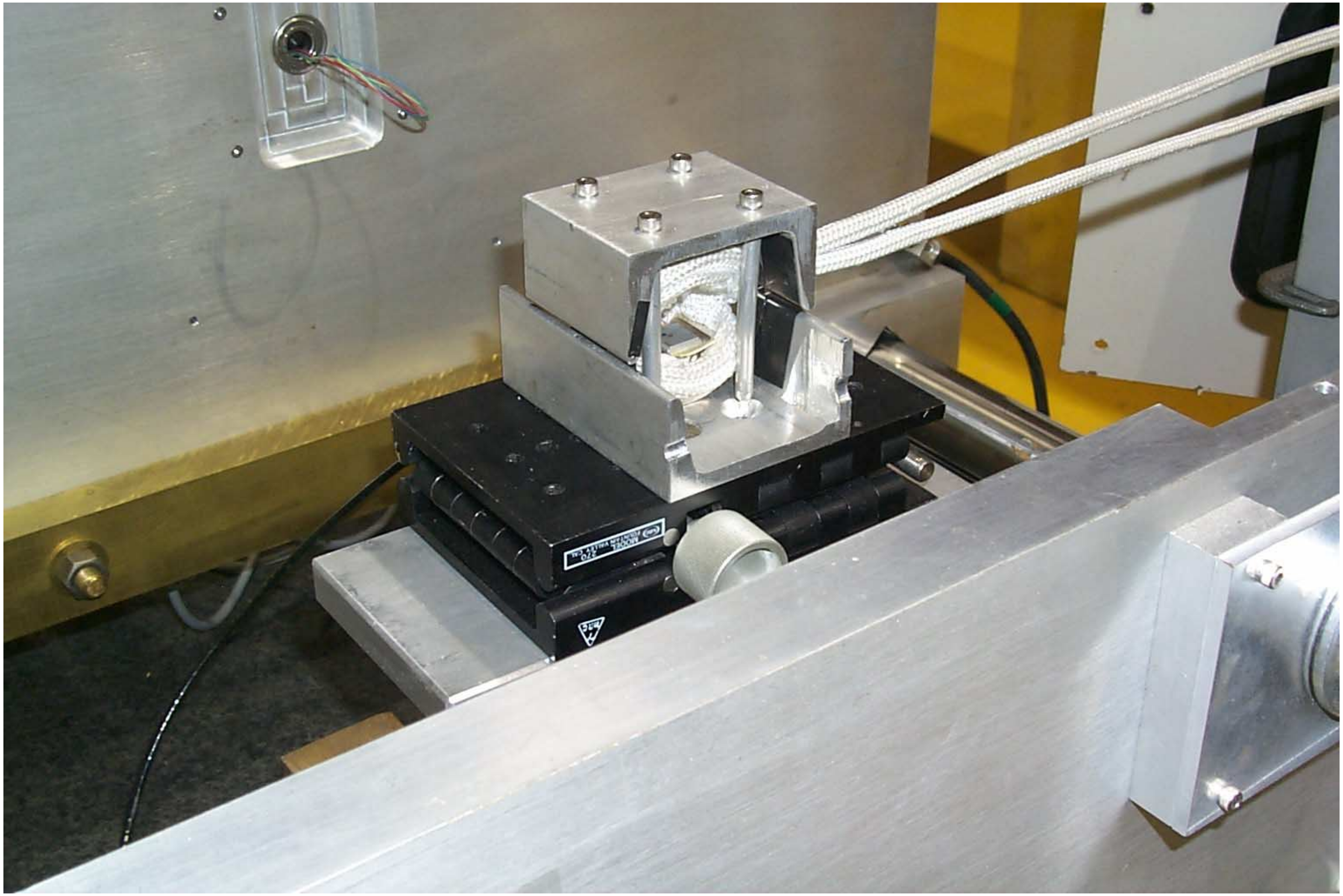
PROBLEM DATA
DTLSM_Symtrc.st
Quadratic elements
XY symmetry
Vector potential
Magnetic fields
Static solution
Scale factor = 1.0
6173 elements
12458 nodes
11 regions

12/Sep/2000 12:48:50 Page 8

OPERA-2d
Pre and Post-Processor 7.507

Steering Dipoles

Steering Dipoles



Steering Dipoles

Aug. 23 2000

SNS Vertical DTL Steerer after modifications to the yoke.

I	B.dl	Harmonics in % of n=1 at R = 10 mm							
(A)	(G-cm)	n=2	n=3	n=4	n=5	n=6	n=7	n=8	n=9
270.45	1882.4	3.23	1.71	2.78	6.85	0.45	1.07	0.62	1.31
240.59	1681.6	3.03	1.72	2.76	6.85	0.46	1.08	0.61	1.32
210.81	1477.8	2.89	1.71	2.75	6.82	0.45	1.07	0.60	1.29
180.96	1275.5	3.19	1.73	2.73	6.82	0.44	1.07	0.61	1.30
149.92	1060.8	3.09	1.73	2.73	6.82	0.46	1.07	0.62	1.32
120.42	856.9	3.69	1.70	2.74	6.80	0.45	1.07	0.60	1.31
91.08	651.1	2.95	1.69	2.72	6.82	0.46	1.08	0.62	1.32
60.41	436.5	3.57	1.70	2.72	6.84	0.44	1.11	0.64	1.30
30.09	222.5	2.53	1.66	2.66	6.86	0.47	1.05	0.59	1.34
0	10.1	-	-	-	-	-	-	-	-

The magnet was conditioned at a current of 300 A before the start of every measurement sequence.

The uncertainty of this coil B.dl measurement is ±3 %.

Steering Dipoles

Aug. 24 2000

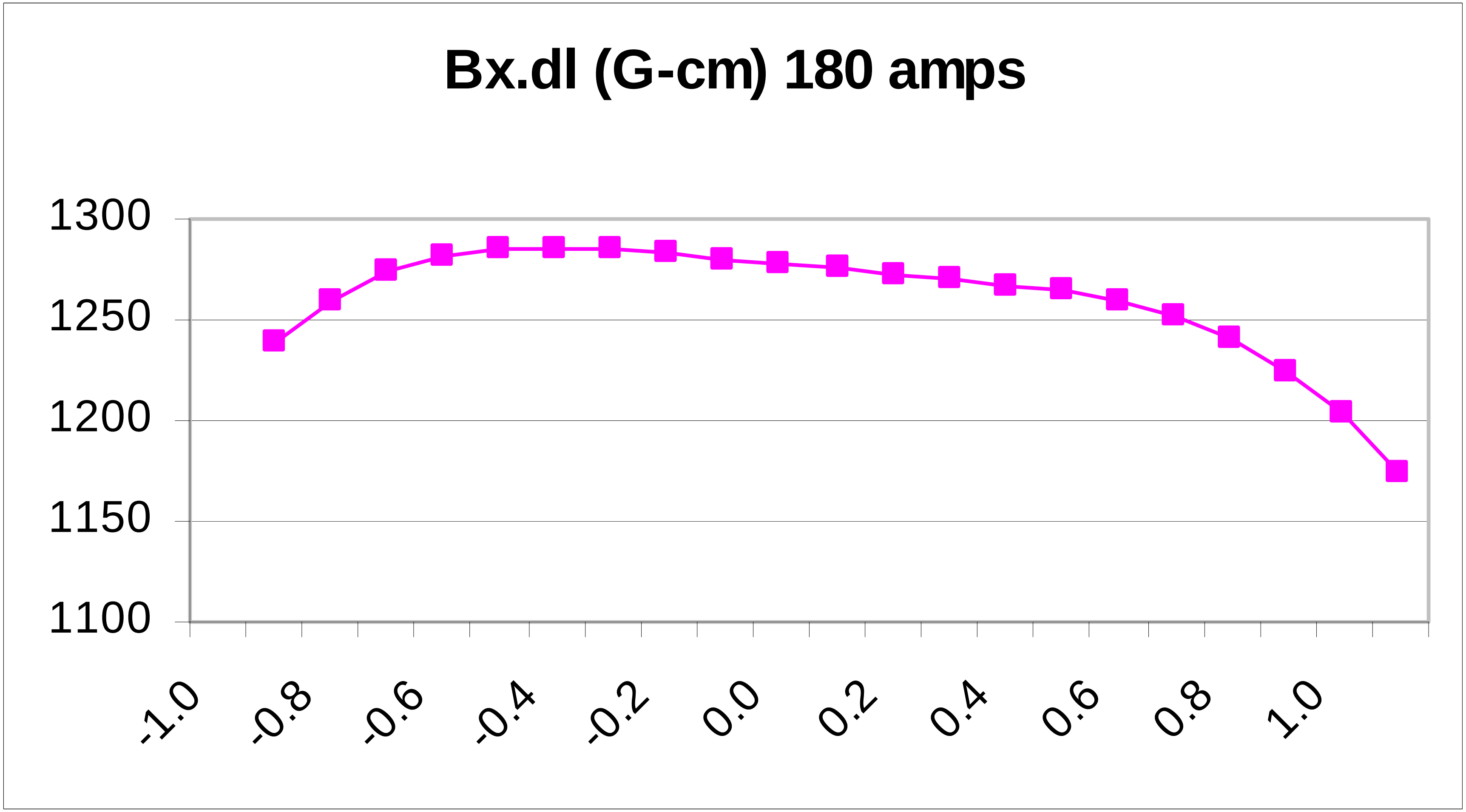
SNS Horizontal DTL Steerer after modifications to the yoke.

I	B.dl	Harmonics in % of n=1 at R = 10 mm							
(A)	(G-cm)	n=2	n=3	n=4	n=5	n=6	n=7	n=8	n=9
270.15	1876.5	1.83	0.22	2.39	3.14	0.77	0.53	1.01	0.61
240.27	1677.5	1.96	1.45	5.51	7.20	1.42	1.87	2.14	1.46
210.28	1474.4	2.06	1.44	5.49	7.19	1.43	1.85	2.14	1.46
180.46	1270.4	1.88	1.47	5.52	7.19	1.41	1.84	2.14	1.45
149.85	1060.7	1.84	1.44	5.50	7.19	1.42	1.84	2.12	1.46
119.93	853.9	1.80	1.46	5.49	7.19	1.41	1.83	2.14	1.45
90.35	646.6	1.93	1.43	5.48	7.15	1.41	1.84	2.14	1.45
60.70	441.9	1.77	1.52	5.46	7.16	1.40	1.82	2.14	1.44
30.57	231.4	1.74	1.59	5.49	7.09	1.43	1.88	2.13	1.44
0	18.7	-	-	-	-	-	-	-	-

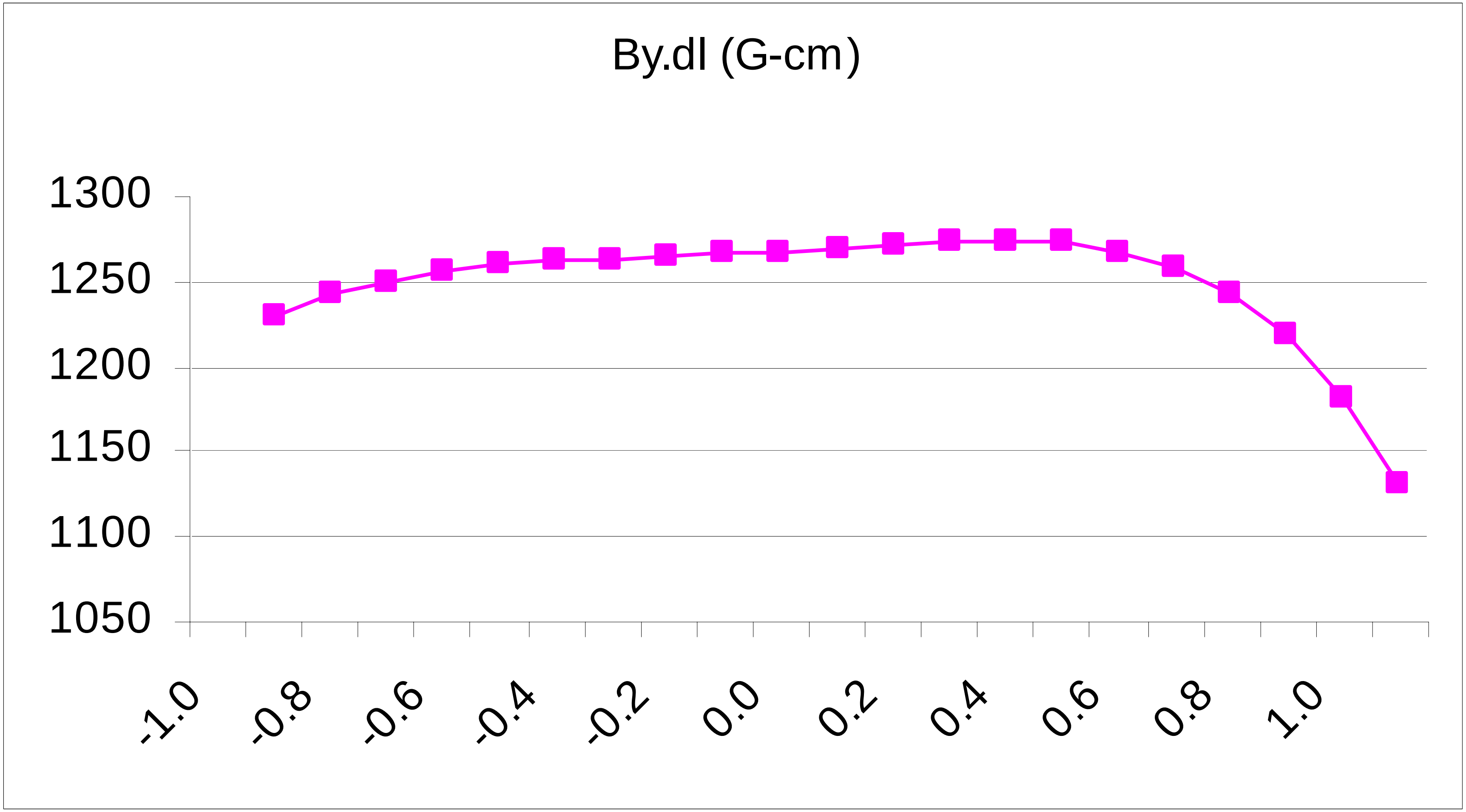
The magnet was conditioned at a current of 300 A before the start of every measurement sequence.

The uncertainty of this coil B.dl measurement is ±3 %.

Steering Dipoles



Steering Dipoles



Steering Dipoles

- **Manufacturing Process**
  - Machine Cores
  - Plate cores
  - Wind & Insulate coils
  - Assemble coils into Cores
  - Flow checks/Ground insulation checks
  - Pot assembly with Ceramic
  - Repeat Flow/Ground checks
  - Ship completed magnet
  - Assemble H/V Magnet into H/V Drift Tube
  - Weld/Furnace Braze Assembly
  - Repeat Flow/Ground checks
  - Add current flags & water fittings
  - Ship completed Drift Tube Assembly
  - Magnetic testing

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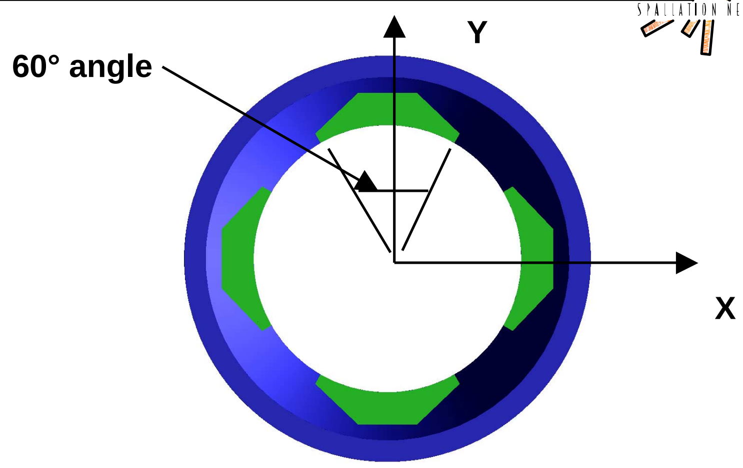
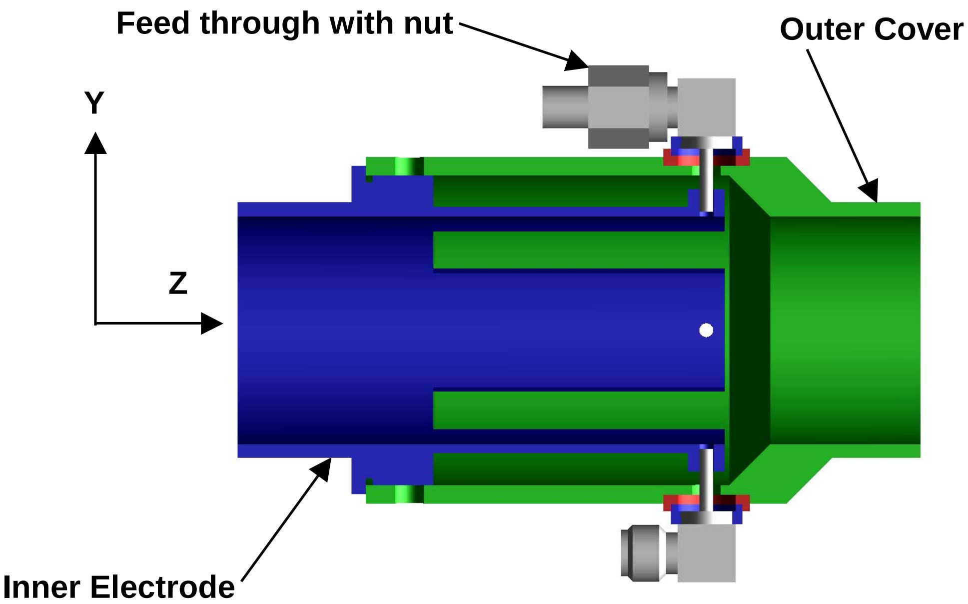
Combined Beam Position Monitor & Beam Phase Detectors

Jim O'Hara

DTL Beam Position Monitor

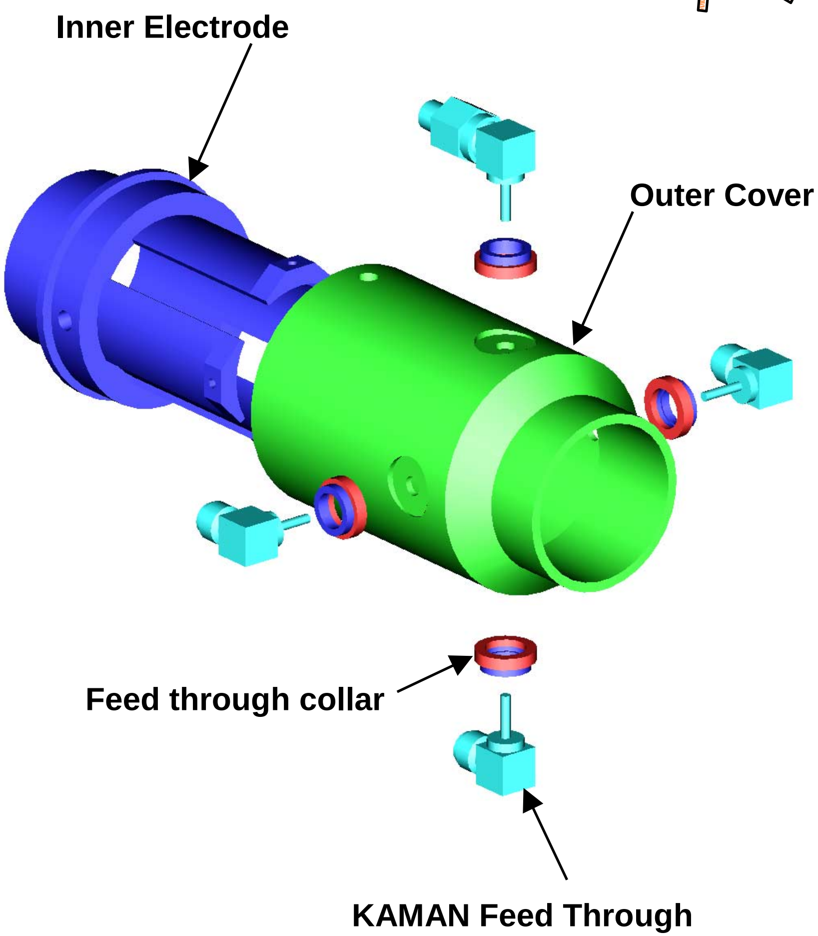
- **Beam line instrument consists of outer cover and inner electrode parts.**
- **Inner part has four, 60° included angle, strip-line electrodes, shorted at one end.**
- **Electrodes flush with drift tube ID.**
- **Geometry is optimized to form 50-Ω impedance transmission line.**
- **Signal from electrodes is taken out through outer cover and drift tube stem.**
- **SMA vacuum feed through is used to provide vacuum seal (Al_2O_3 strengthened boro-silicate seal).**





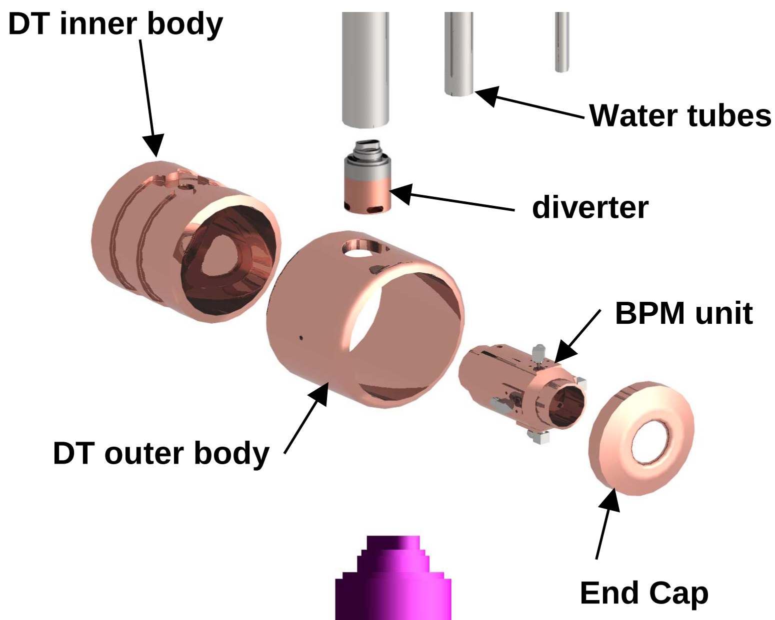
DTL BPM Fabrication and Assembly

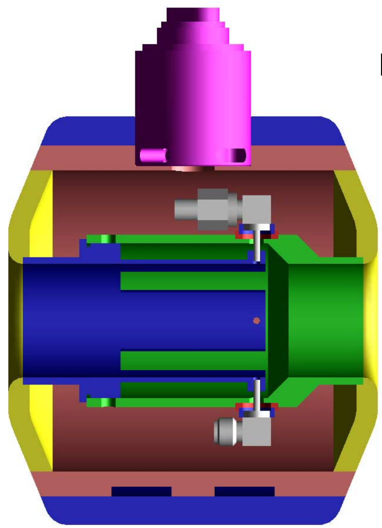
- BPM outer cover and inner electrode parts are brazed together.
- Dowel pins are used to correctly clock the two parts.
- Feed through sub-assembly installed next.
- Stainless to copper transition piece is needed between feed through and outer cover.
- Transition piece is brazed together, then welded to feed through on the bench.
- Feed though sub-assembly is welded into place.
- Electrical contact is ensured by soldering feed through center pin to electrode.



DTL BPM Fabrication and Assembly

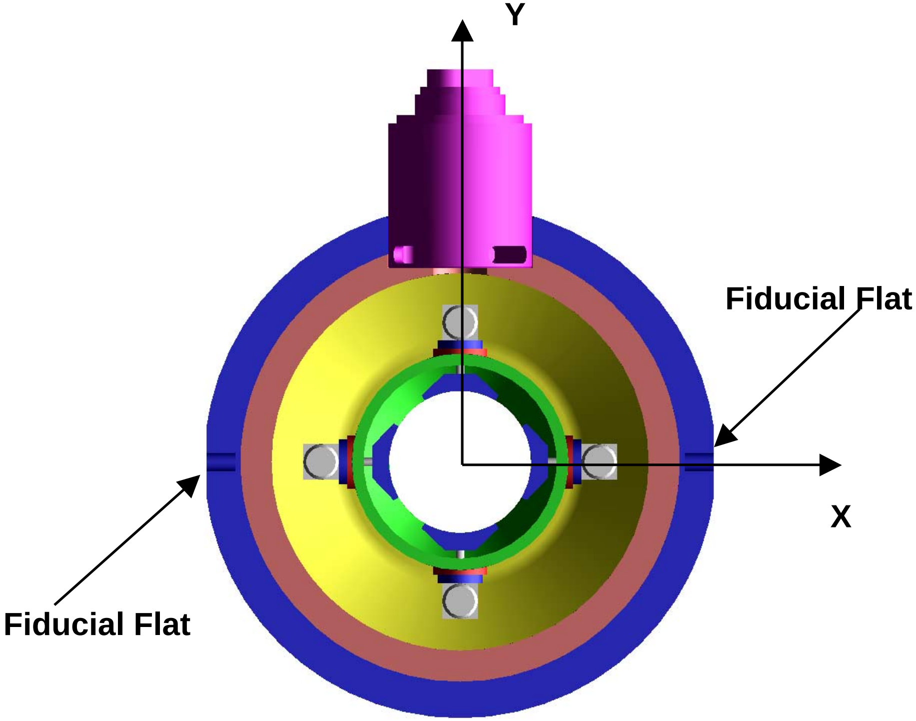
- BPM unit will be delivered to Drift Tube fabricator for installation in DT.
- Assembly process has been previously described, will be similar to the PMQ assembly.
- Signal cables will be threaded through the Drift Tube stem and connected to feed throughs, prior to welding on of end caps.
- Cables will need to be secured while drift tube undergoes final machining of the faces.
- Alignment pins will be used to provide proper roll orientation of the instrument in the Drift Tube.





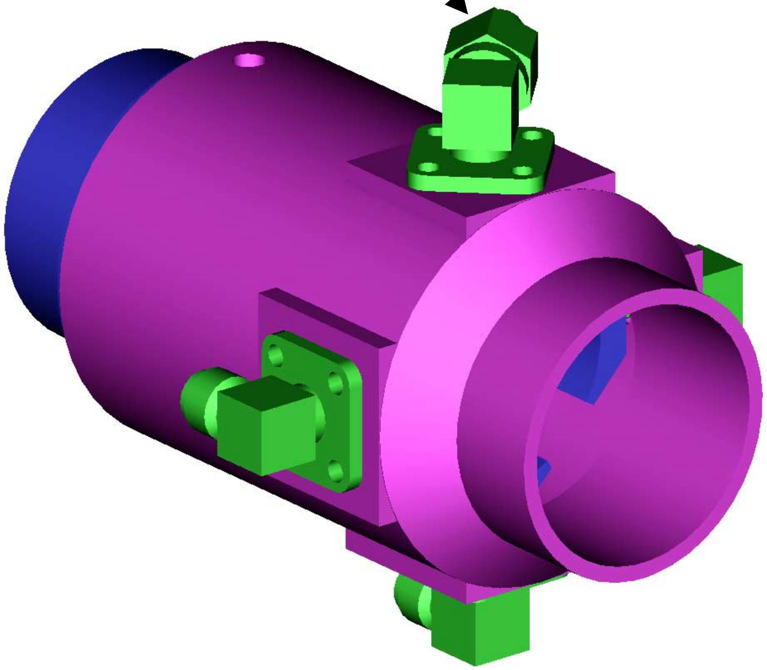
DTL Alignment

- **The drift tube/BPM assembly will be mapped (taut wire measurement) with reference to the fiducial features in the lab.**
- **Alignment of the drift tube/BPM assembly will be accomplished by using the two fiducial holes in the side of the drift tube.**
- **It will be necessary to insure the BPM is clocked in the drift tube so that the fiducial holes line up with the horizontal electrodes.**
- **The plan is to have a pin in the drift tube end cap and a groove in the BPM body, so that when the two parts go together roll will be controlled.**



DTL BPM Prototype

- **A prototype of the DTL BPM is being fabricated.**
- **Need to test the response of the BPM before and after installation into the drift tube.**
- **Need to insure the ability to thread coax lines back through diverter tube.**
- **The KAMAN feed through is a long lead item (6 month delivery), so the prototype will be built with a different type of feed through.**



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DTL tanks and components

Tom Ilg

Outline

- Tanks
- Tank plating
- Post couplers
- Slug tuners
- Endwalls
- Vacuum pump spools
- Monitor loops

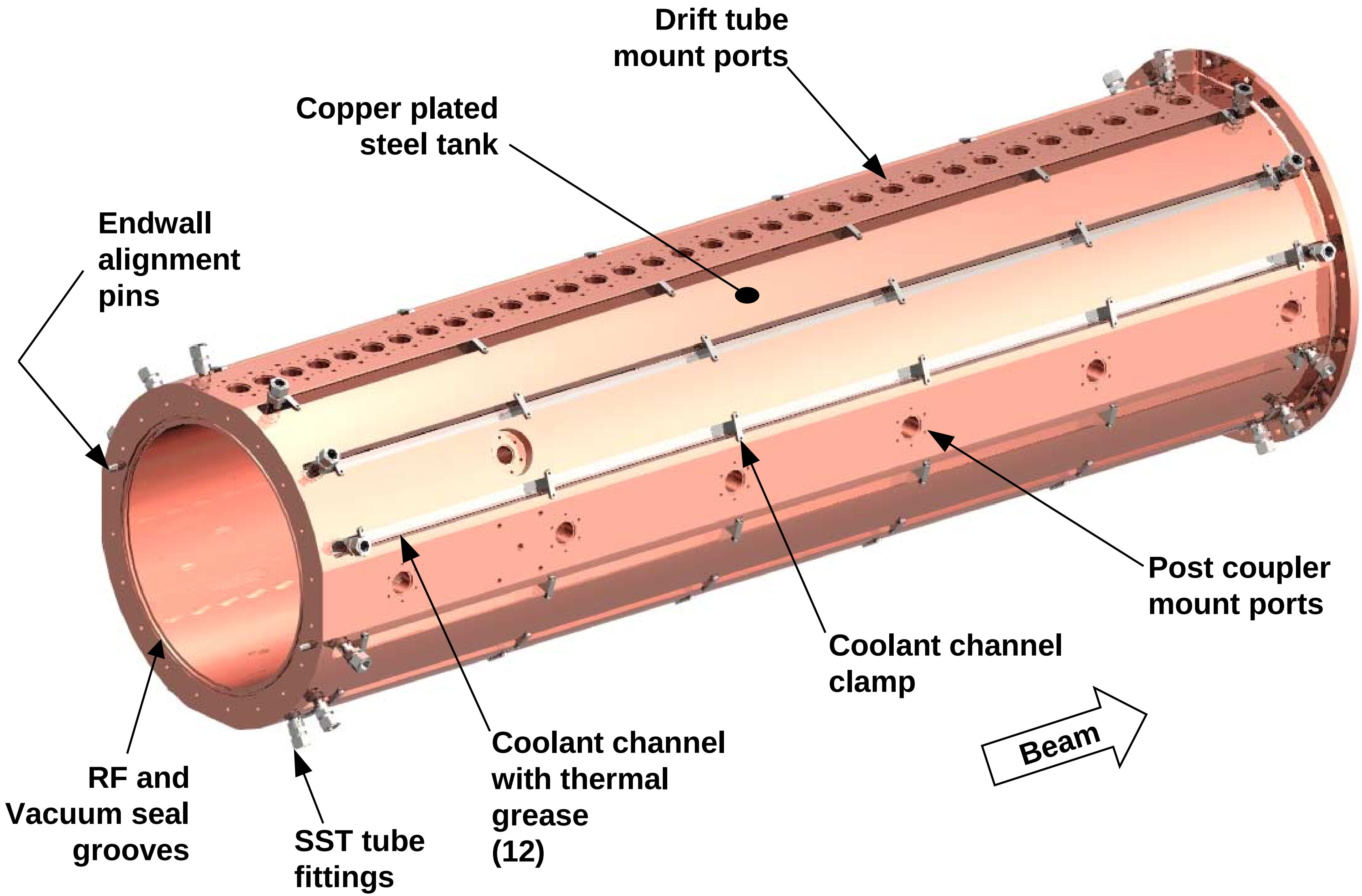
DTL Tank Functions and Features

- Provides a resonance cavity.
- Provides a vacuum environment enclosure.
- Provides a stable platform for drift tubes, post couplers, and slug tuners.
- Provides mounting surfaces for vacuum pumps and portions of the water system.
- Provides mounting locations for alignment targets for proper positioning in the tunnel.
- DTL tank 1 is made from 2 sections.
- DTL tanks 2 thru 6 are made from 3 sections.
- Tank sections are made from carbon steel because of lower costs versus other potential materials, i.e. aluminum and stainless steel.

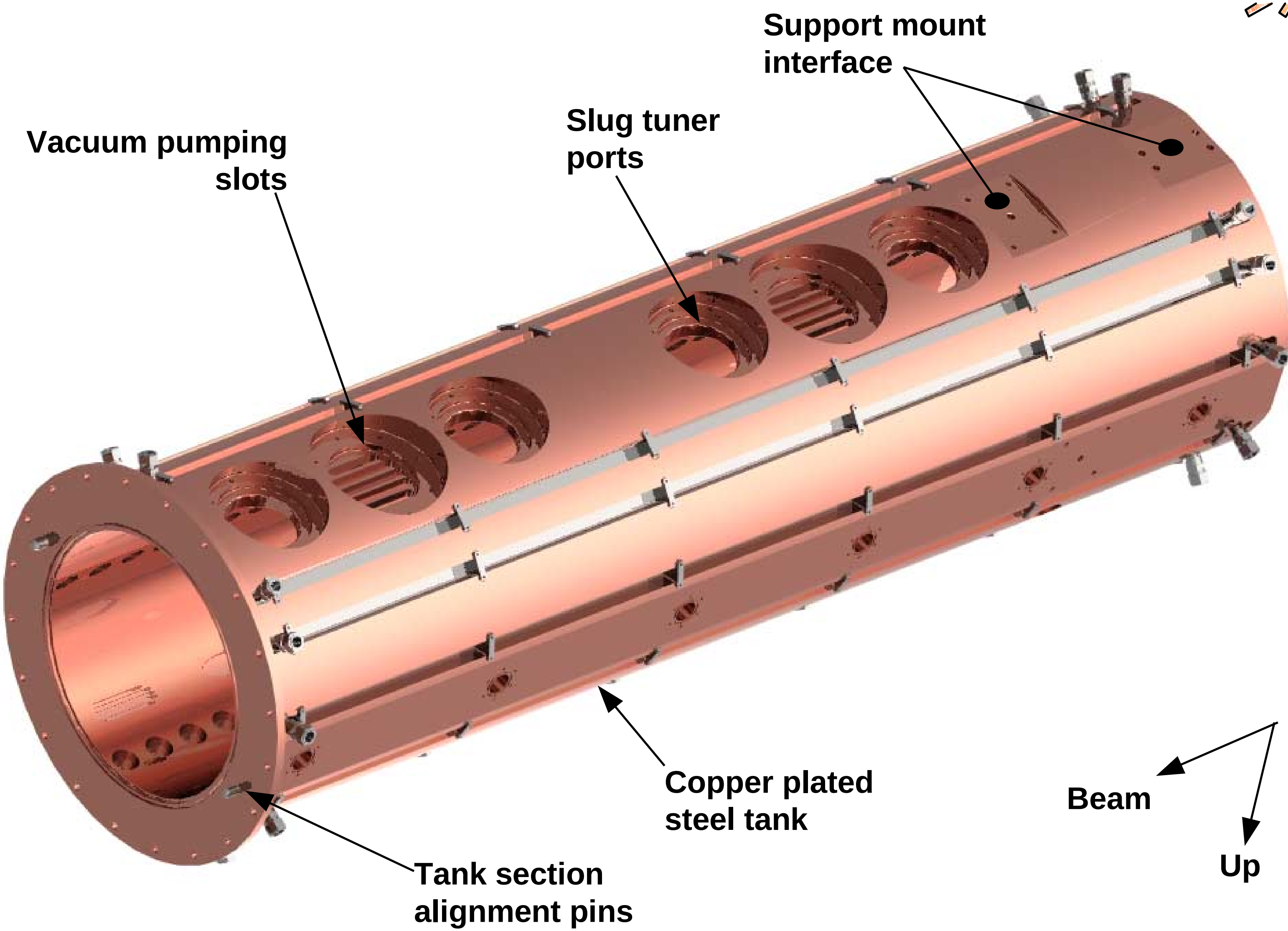
DTL Tank Functions and Features

- **General tank section size.**
  - 17” ID x 22.5 OD x 7ft long.
  - Approximate weight per tank section = 3000 lbs.
- **Tank sections are bolted together using vacuum and RF seals at the interfaces.**
- **Coolant channels are embedded longitudinally with a thermal grease to enhance heat transfer.**
- **No welding is required on the tank sections this increases material stability and reduces plating difficulty.**

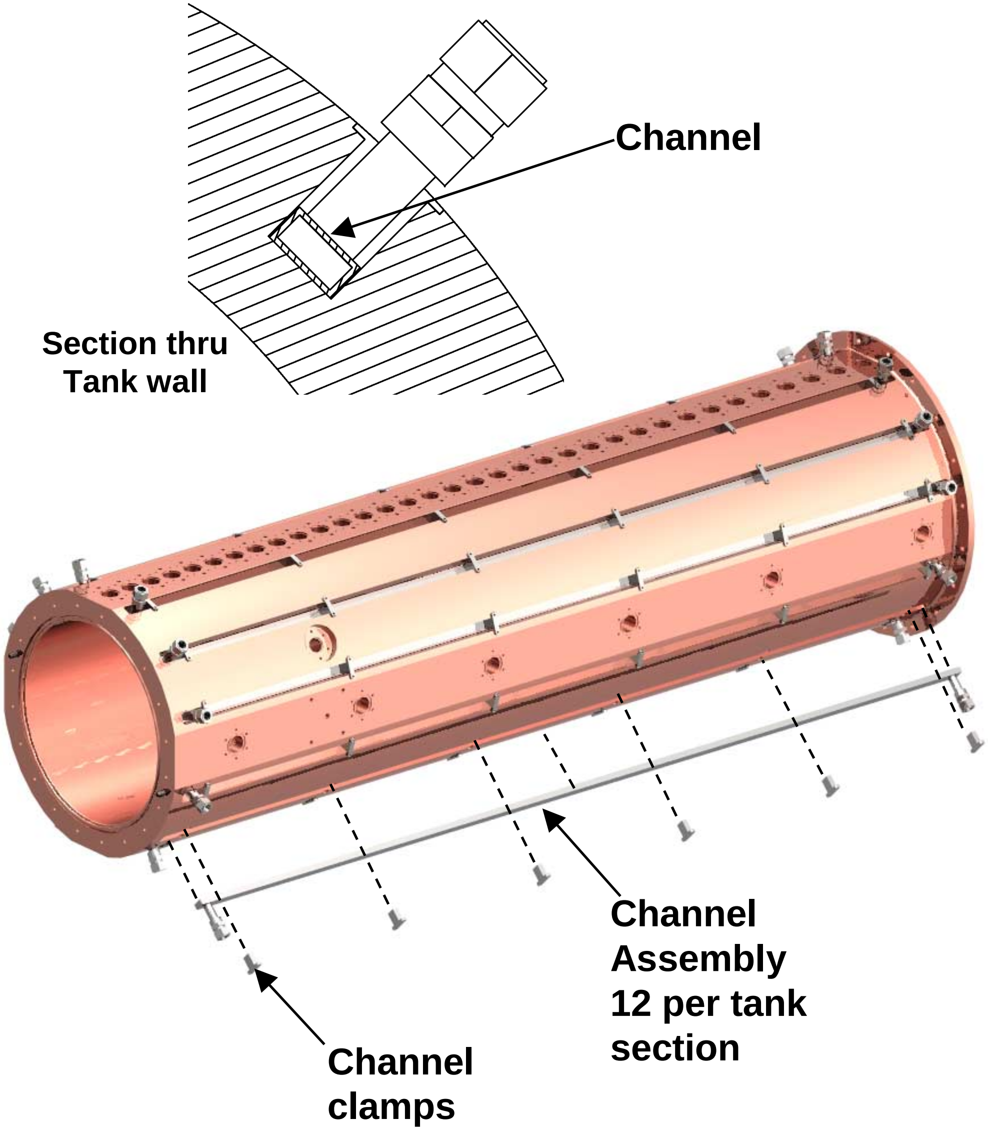
DTL Tank Section 1A



DTL Section Tank 1A (con't)

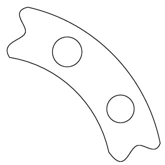
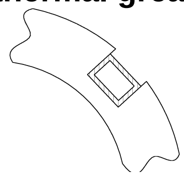
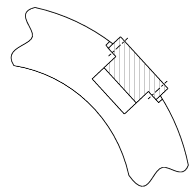
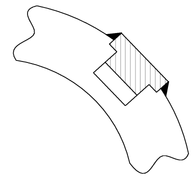


Tank Coolant Channels



- Provides temperature control of tank walls.
- Individual channel flow rates range from 1.6 gpm to 6.6 gpm using a once-thru counter flow scheme.
- Non-silicone based thermal grease is used to enhanced heat transfer between tank and channels.
- Embedded channels provide a closed flow system and prevents water contact with carbon steel surfaces.
- All welded 304L SST construction using 1” x ½” rectangular tubing.

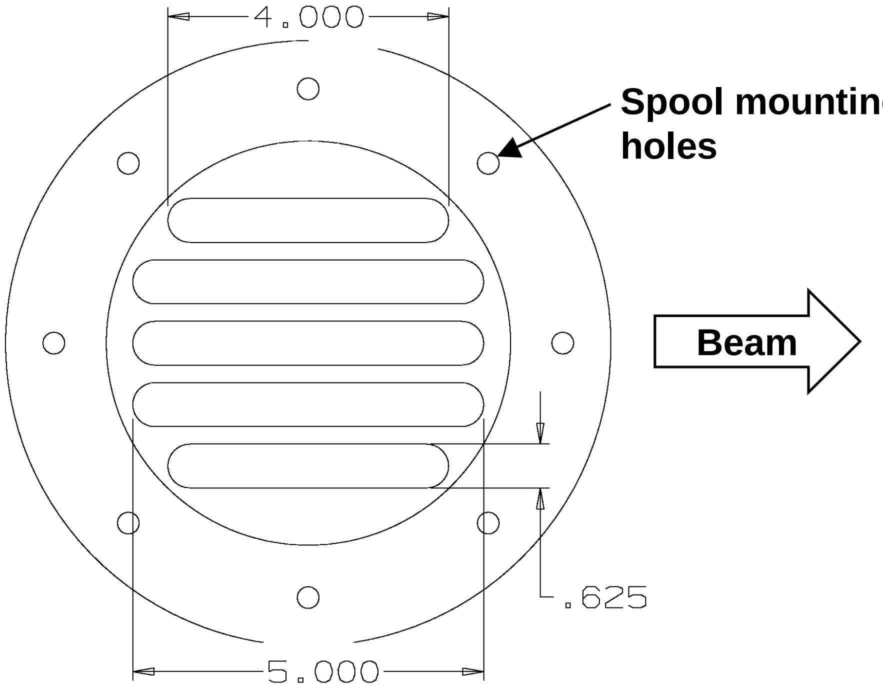
Tank Channel options - Qualitative Comparison

Rating 5- very good 4 - Good 3 - Fair 2 – Poor 1- Very poor	**Deep drill holes with ends plugged and welded** 	**Trough with square or rectangle channels clamped in place with thermal grease** 	**Trough with cover flange bolted in place with gasket** 	**Trough with cover flange welded in place** 
Heat transfer	**5**	**3.5**	**5**	**5**
Accessibility and maintenance	**1.5**	**3.5**	**5**	**1**
Corrosion prevention	**1**	**5**	**1**	**1**
Reliability **i.e. leaking**	**3.5**	**5**	**3**	**3.5**
Fabrication **risk**	**2**	**3.5**	**4**	**3**
Cost	**2**	**4**	**2**	**3**
Total	**15**	**24.5**	**20**	**16.5**

Design option chosen

Vacuum Pumping Slots

- **Provides 1145 L/s of conductance.**
- **Slots keep RF fields low in pumping ports.**
- **Slot configuration is located at each pumping port.**

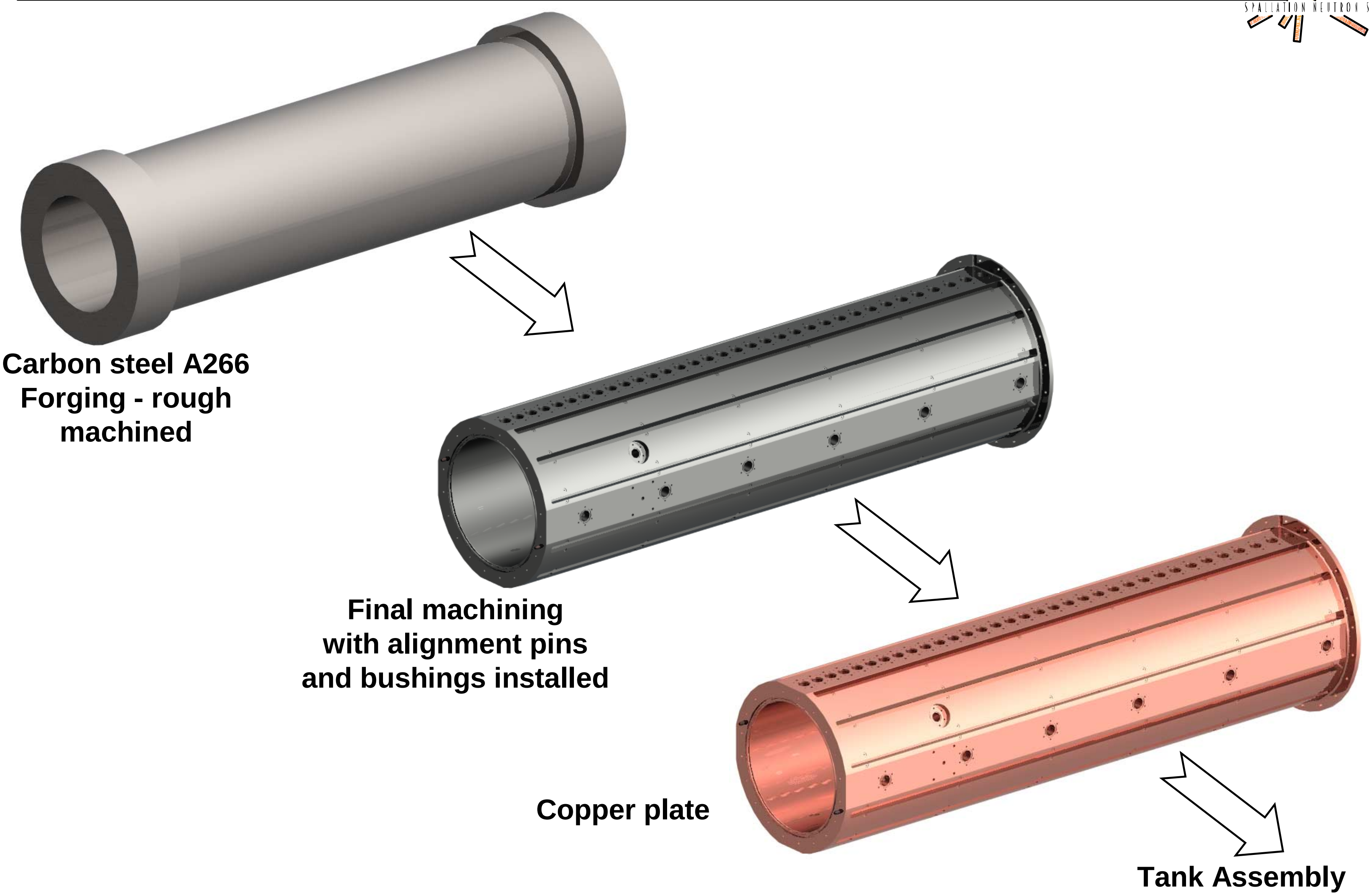


View looking up

DTL Tank Section Fabrication

- **Tank sections are to be made out of Carbon steel forgings per ASTM A266 grade 2 (specification for Carbon steel forgings for pressure vessel components).**
  – Normalized condition
  – Ultrasonic tested per ASTM A388 with no detectable flaws
  – Macro-etched tested to show flow lines and internal imperfections on sample forgings
  – Tensile yield strength = 36 ksi
  – Tensile ultimate strength = 70 ksi
- **Tanks sections are to be machined using CAD part flies, i.e. IGES, STEP, and/or Unigraphics part flies.**
- **Tank sections are to be electroplated with copper inside and out to .002" to .003" (50µm to 80µm).**

DTL Tank Section General Fabrication Process



DTL Tank Plating Plan

- **Tanks to be plated at GSI (Gesellschaft für Schwerionenfschung) in Darmstadt Germany using GSI's standard plating process for accelerator components.**
- **Advantages of plating at GSI.**
  - Experienced in copper plating accelerator components
  - Little or no development work is required
  - Plating process is inexpensive
  - Plating process is quick – approximately 2 tank sections per week
- **Disadvantages of plating at GSI.**
  - SNS must supply the labor and learn the plating process from GSI
  - Shipping costs
  - Travel expenses
- **Copper test piece to be plated at GSI in October 2000.**
  - 2 week duration
- **Production tank plating to start September 2001.**
  - 3 months duration

Tank Plating Test Piece

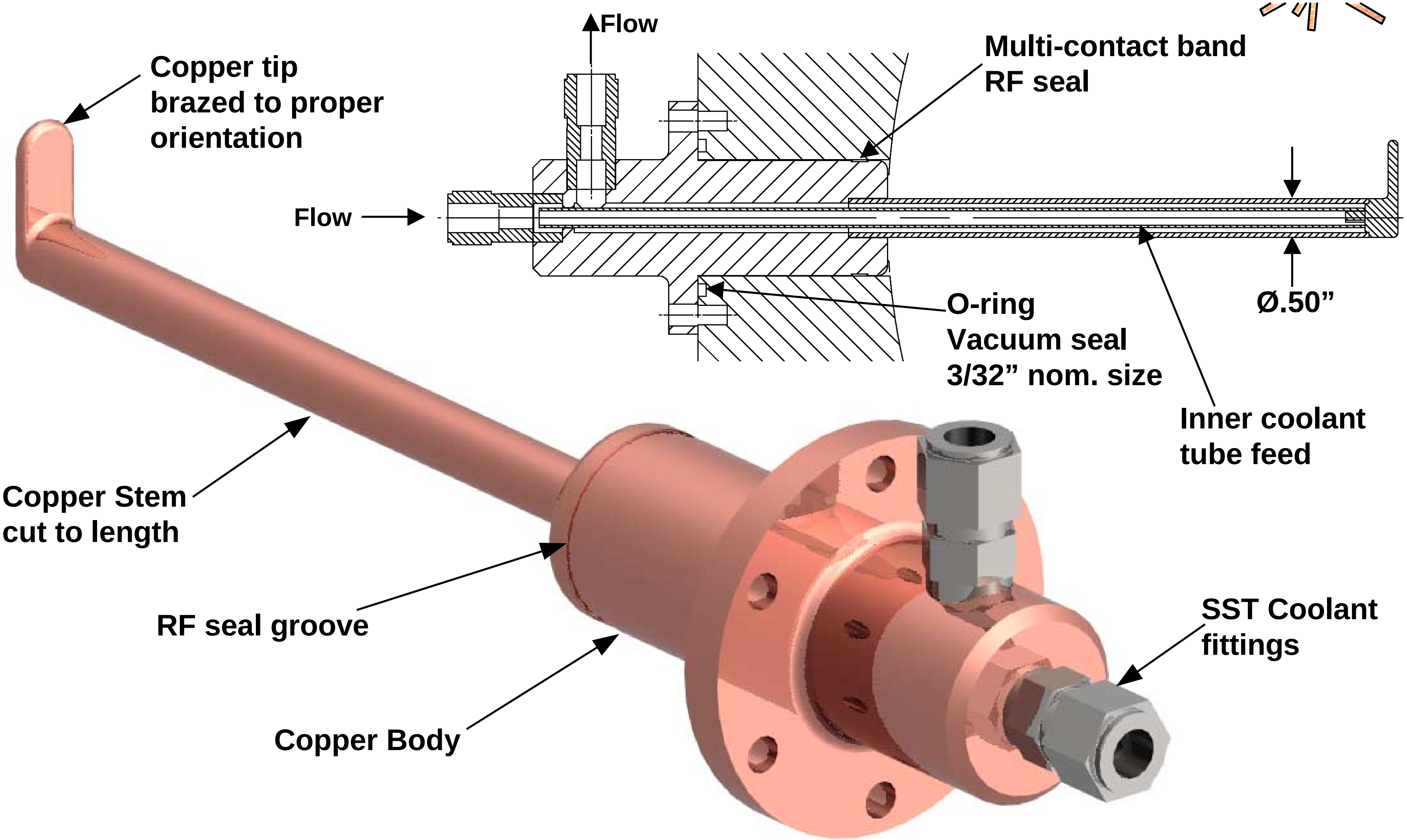
Seamless steel pipe ASTM A106B
20” OD x 1.5” wall x 8’ long

Machined part prior to plating

Post Coupler Design

- Post couplers provide longitudinal stability to the tank electric field by providing a transverse field that couples with the drift tube body.
- Post couplers are water cooled because they carry significant RF currents.
- Each Post coupler will require a unique penetration and rotational position. The required adjustment is determined and measured from the low power tuning process using aluminum dummy post couplers.
- Final Post couplers are cut to size and brazed and installed in the correct orientation.
- Post couplers are OFE copper brazed construction with stainless steel water fittings.
- Post coupler are located at every third drift tube in tank 1.
- Baseline shape is a straight stem, bent stems are being investigated in the cold model.

Post Coupler Design

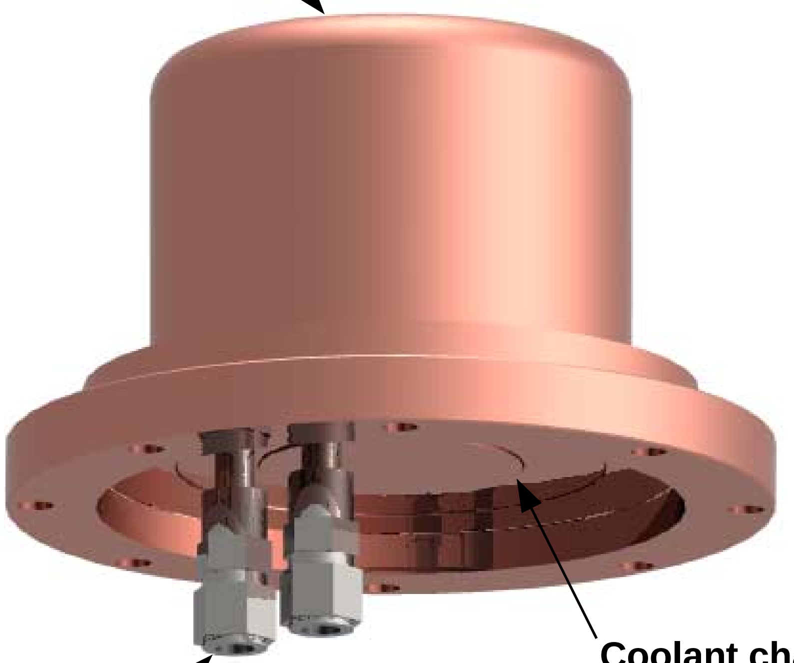


Brazed Assembly

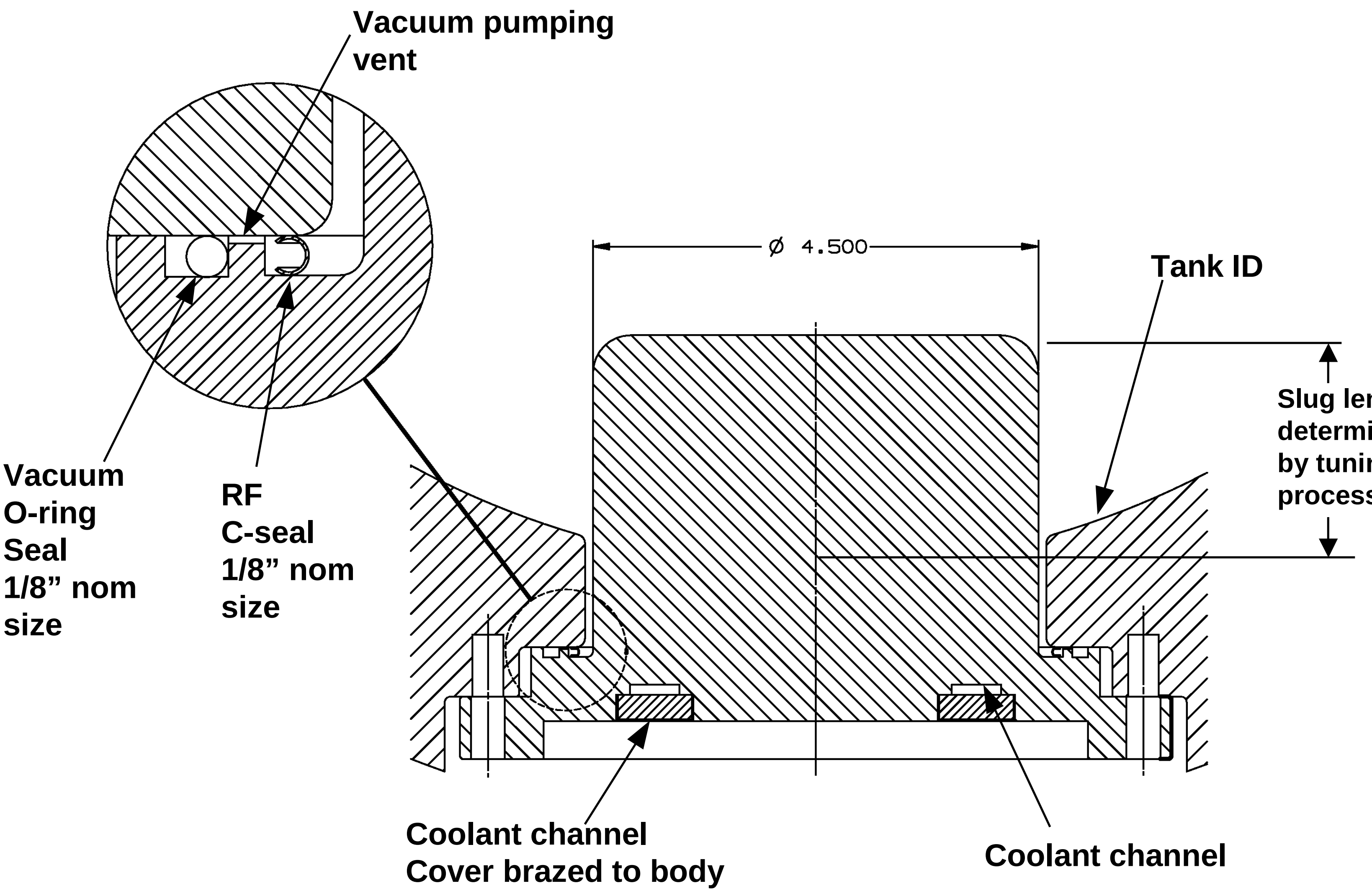
Slug Tuner Design

- Slug tuners provide static frequency adjustment to the RF cavity.
- Tuning range for 3” penetration is 110 kHz to 440 kHz per slug tuner.
- Each DTL tank will have 12 slug tuners (Tank 1 will have 8).
- Slug tuner penetration length is determined by aluminum dummy slug tuners used in the low power tuning process.
- Slug tuners are OFE copper brazed construction with stainless steel water fittings.
- Slug tuners are water cooled because they carry significant RF currents.
- Diamond tipped cutting tools are used to achieve high quality surfaces.

Slug Tuner Design (con't)



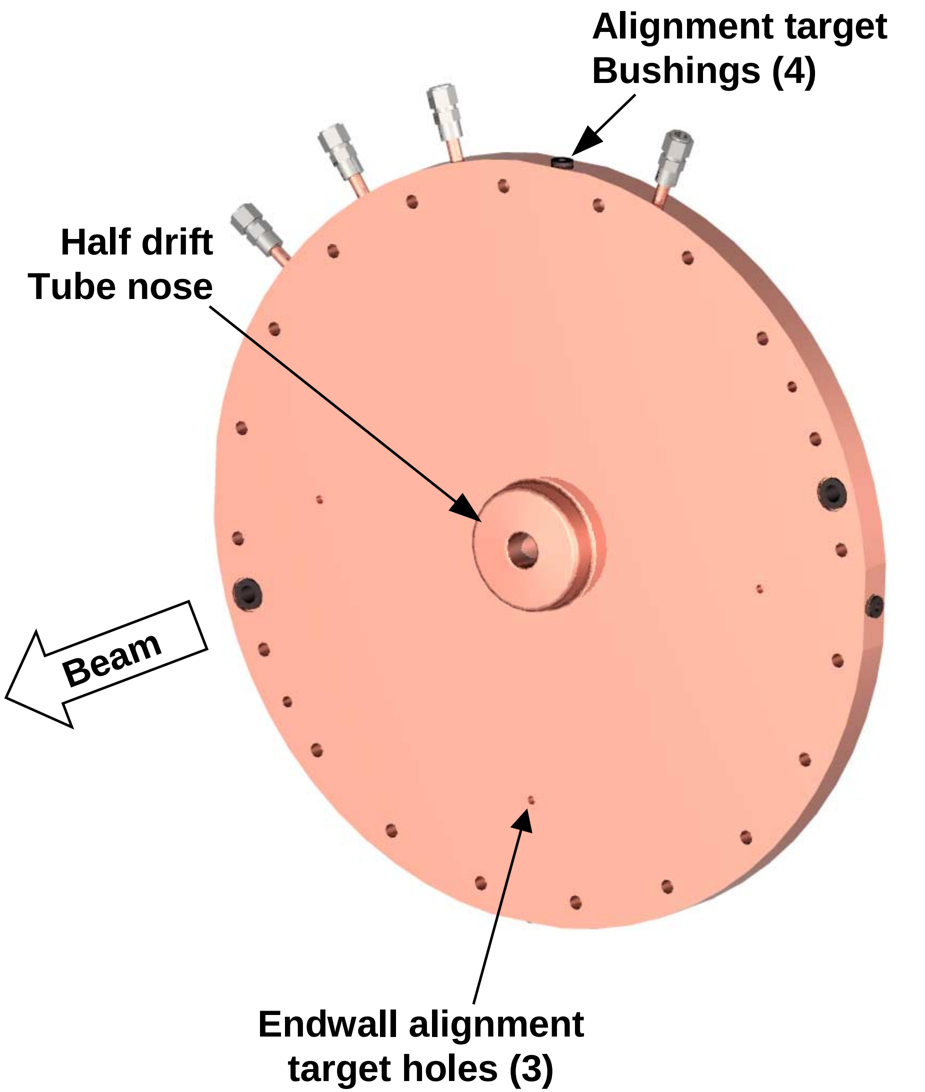
Slug Tuner Design (con't)

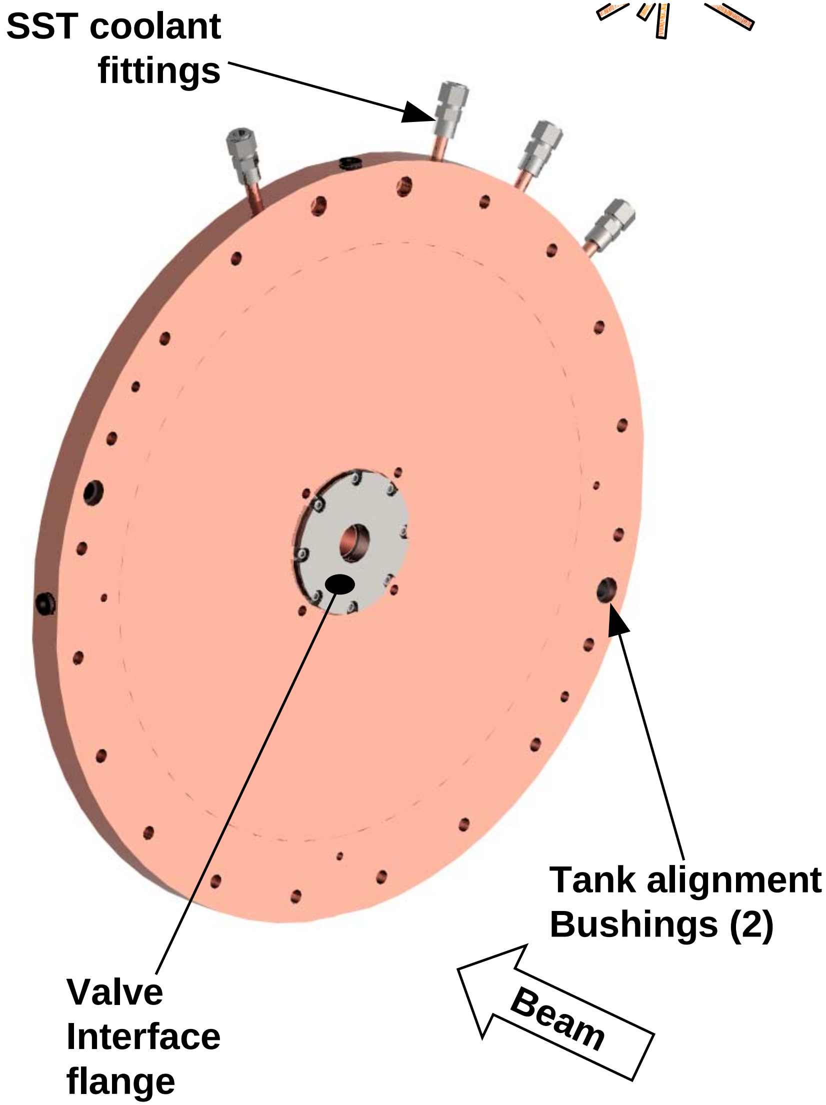


Endwall Requirements and Features

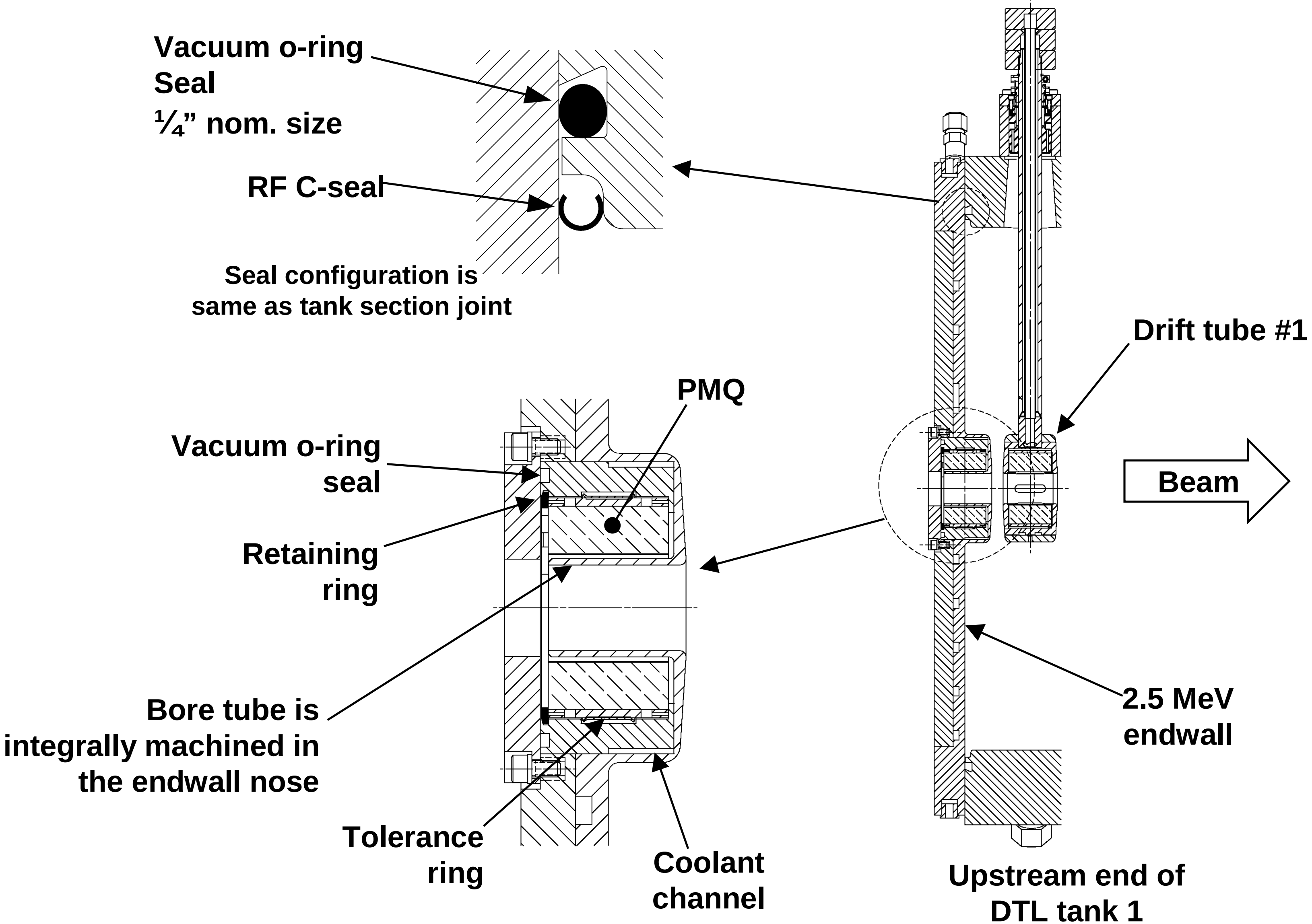
- 12 endwalls are required (2 per DTL tank).
- Endwalls provide tank end vacuum enclosures.
- Completes the upstream and downstream cell geometry (half drift tube geometry).
- Provides a housing for PMQ's, 7 places.
- Provides a housing for Toroids, 5 places.
- Provides mounting holes for alignment targets which are used to define the endwall coordinate origin required to align the drift tubes in the DTL tank. The alignment holes will be mapped to the magnetic center of endwall PMQ using a taut wire measurement.
- Endwall base is made from an OFE copper forging.
- One step brazed construction using a copper-silver braze alloy.
- Diamond tipped cutting tools are used to achieve high quality surfaces.
- Critical surfaces and features are machined after final braze cycle.
- Estimated weight = 100 lbs
  - Crane assist is required for installation

2.5 MeV Endwall (Tank 1 Upstream Endwall)

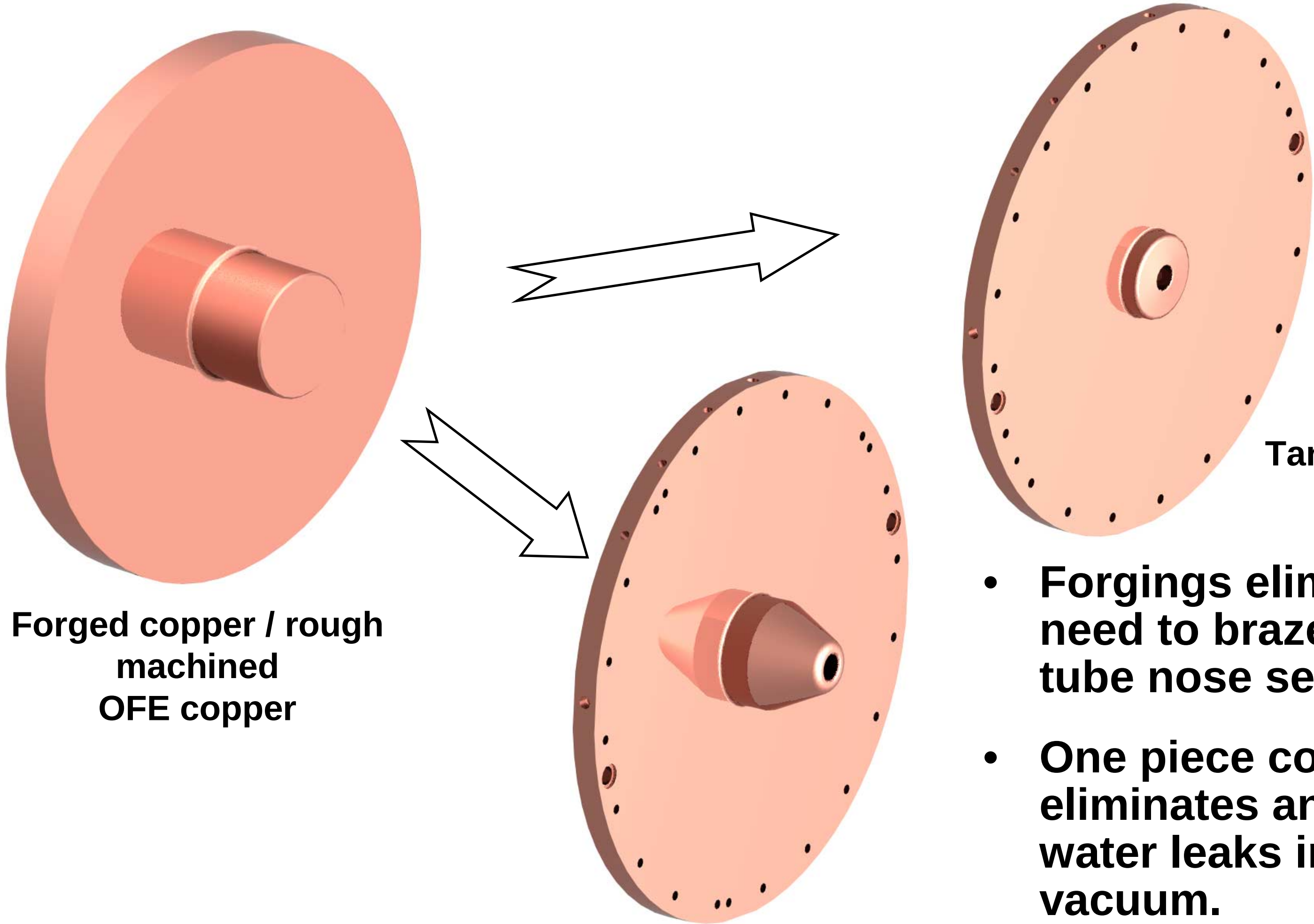




2.5 MeV Endwall (con't)

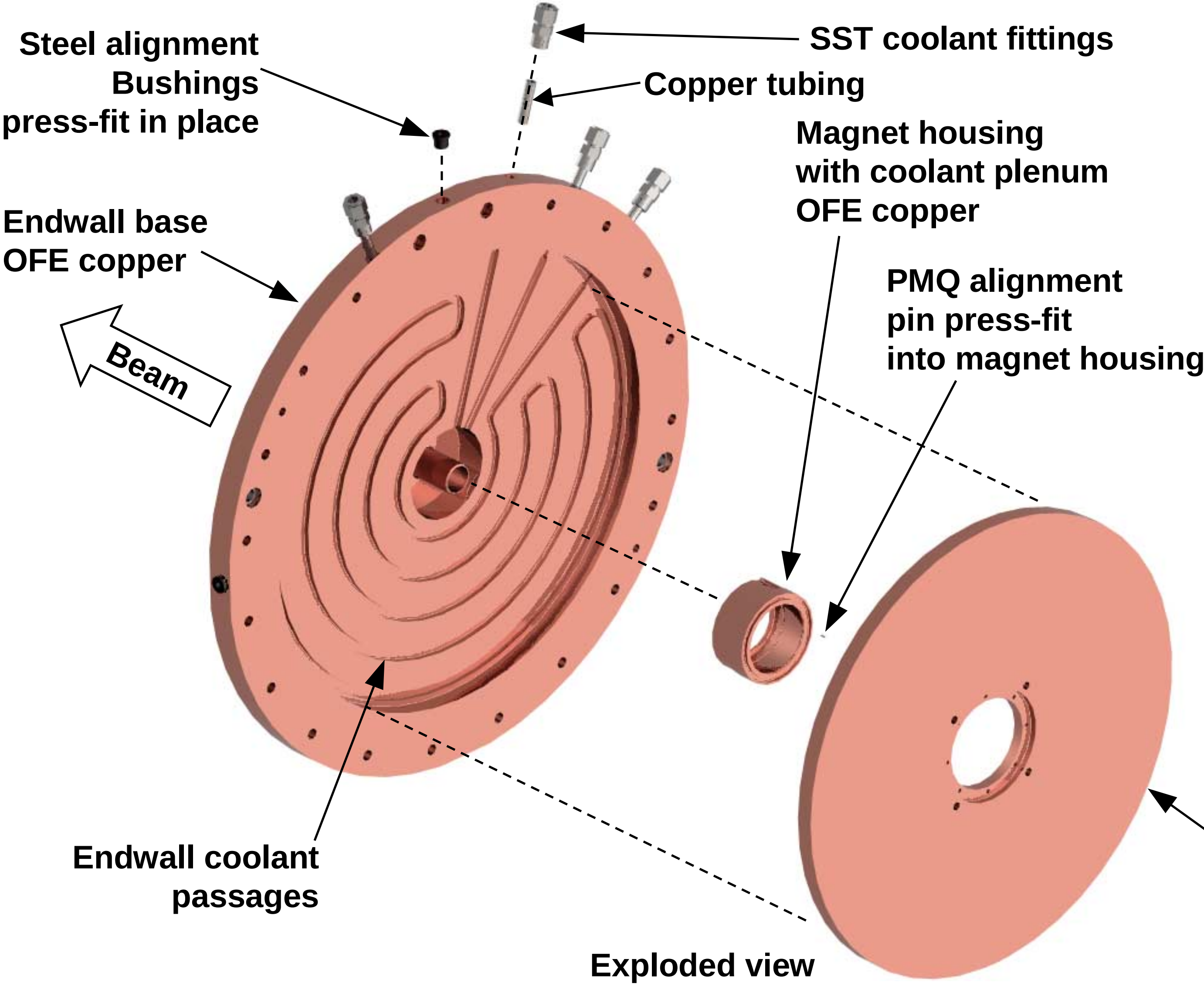


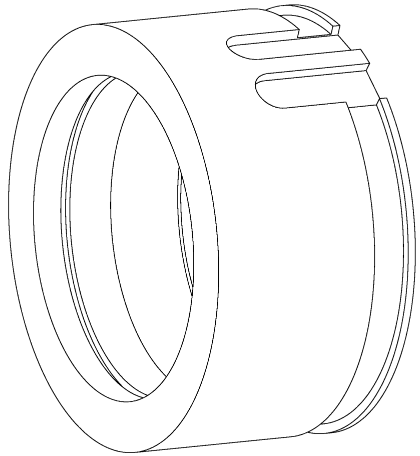
Endwall Fabrication and Design



- **Forgings eliminates the need to braze on the drift tube nose separately.**
- **One piece construction eliminates any possible water leaks into the tank vacuum.**
- **Nose height varies from .889” to 3.768”.**

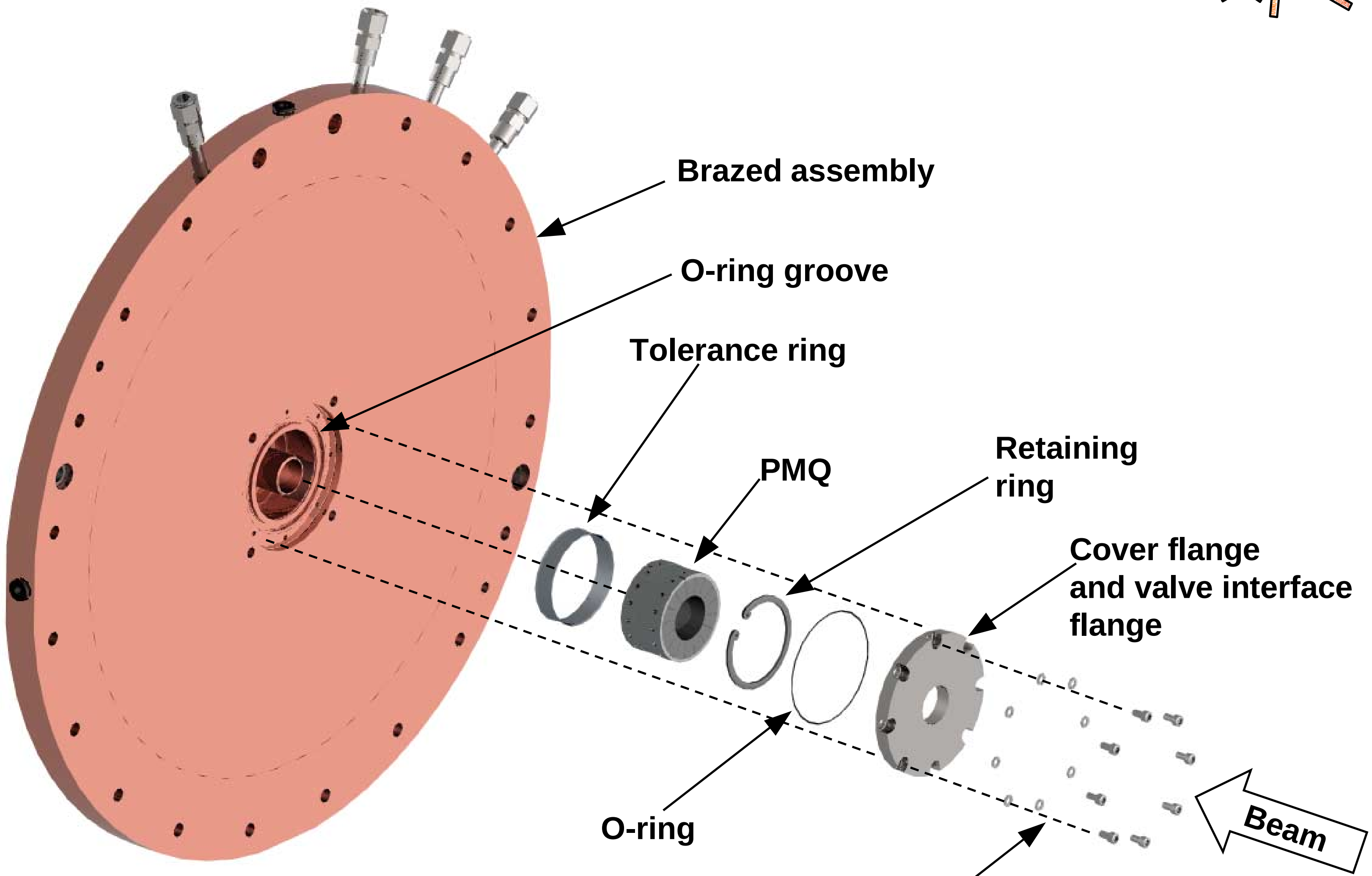
Tank 1 Upstream Endwall Braze Assembly





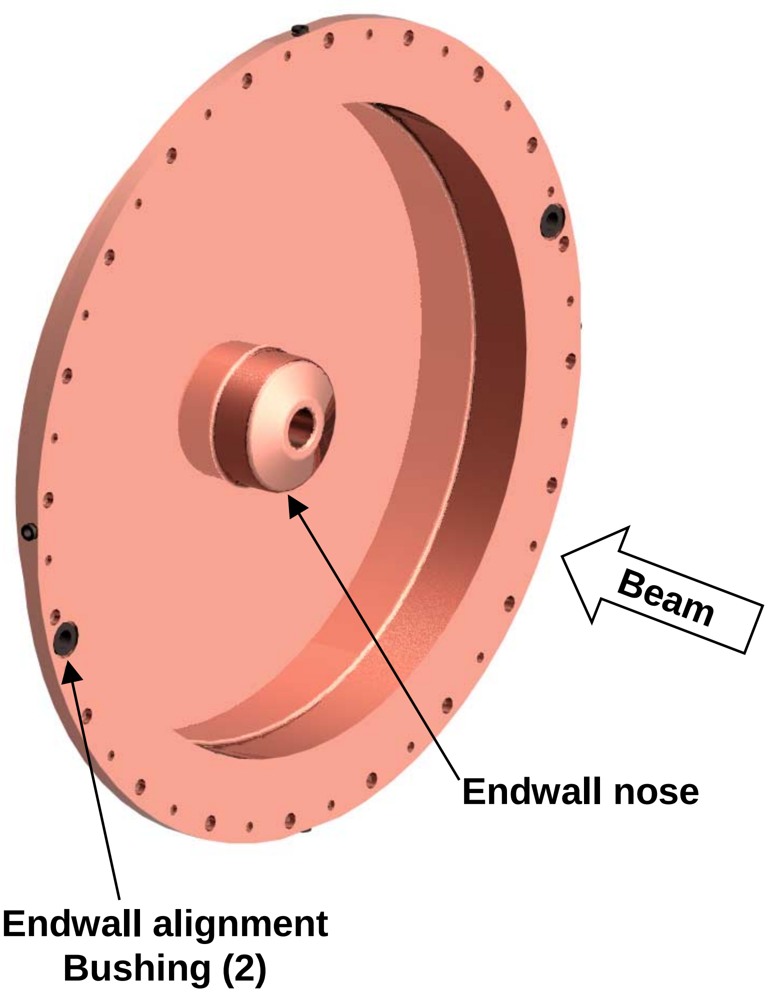
Magnet housing with coolant plenum

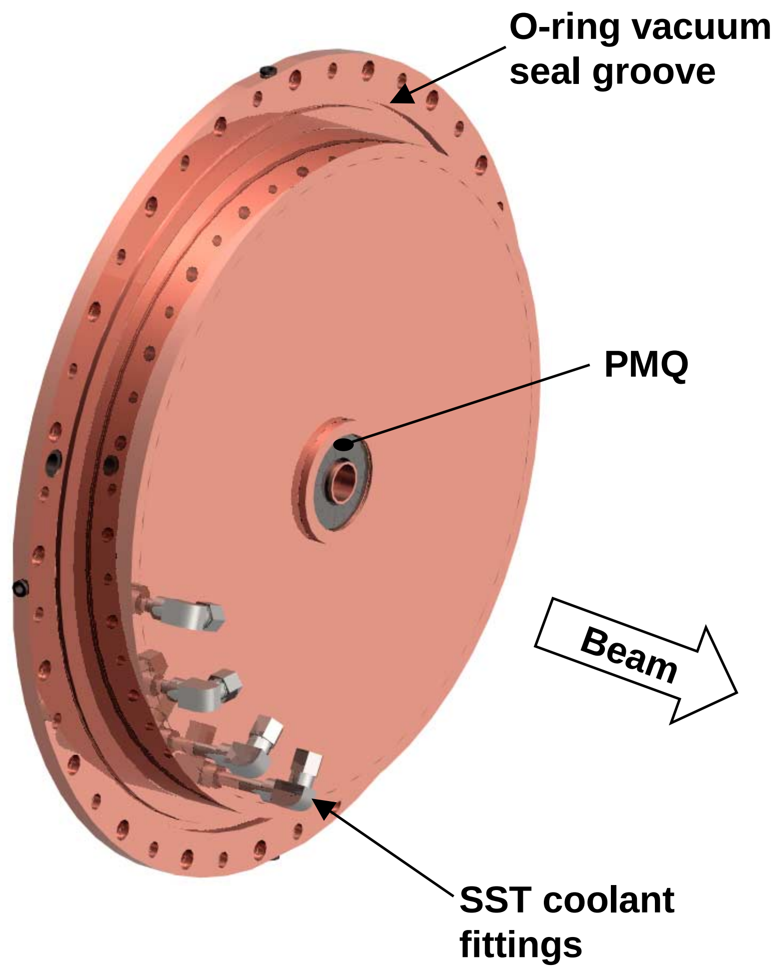
Tank 1 Upstream Endwall Assembly



Exploded view

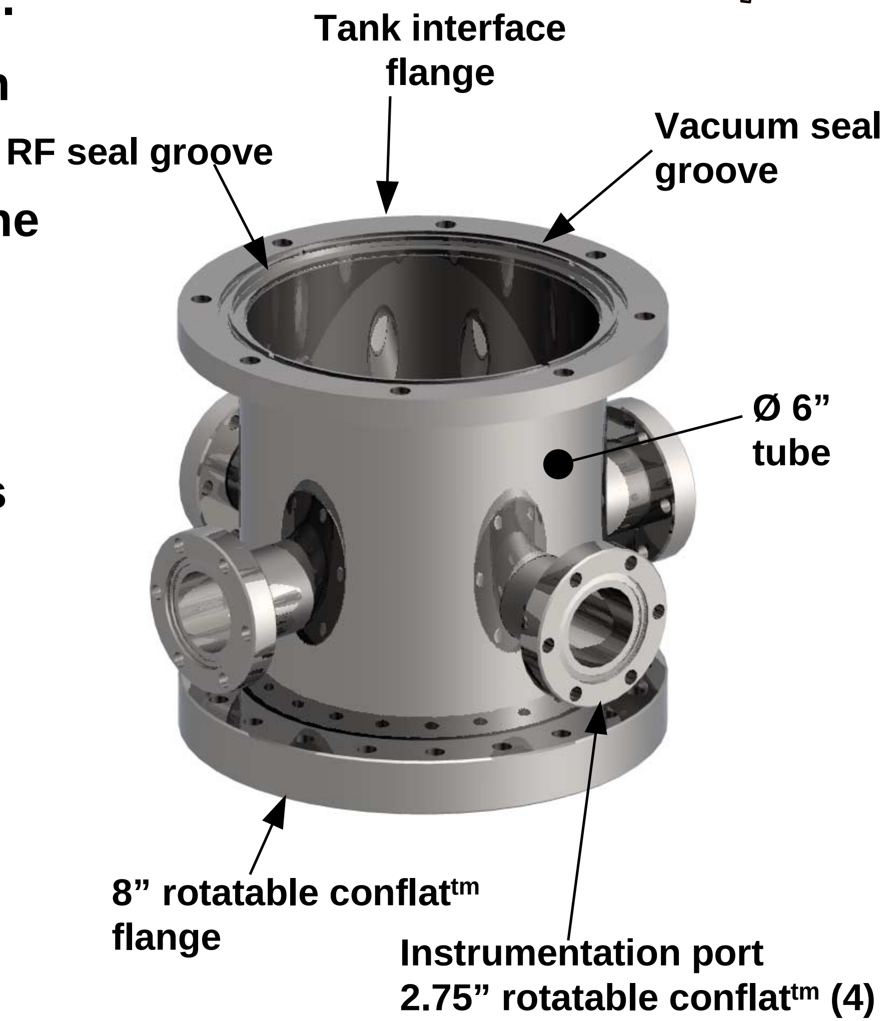
Tank 1 Downstream Endwall





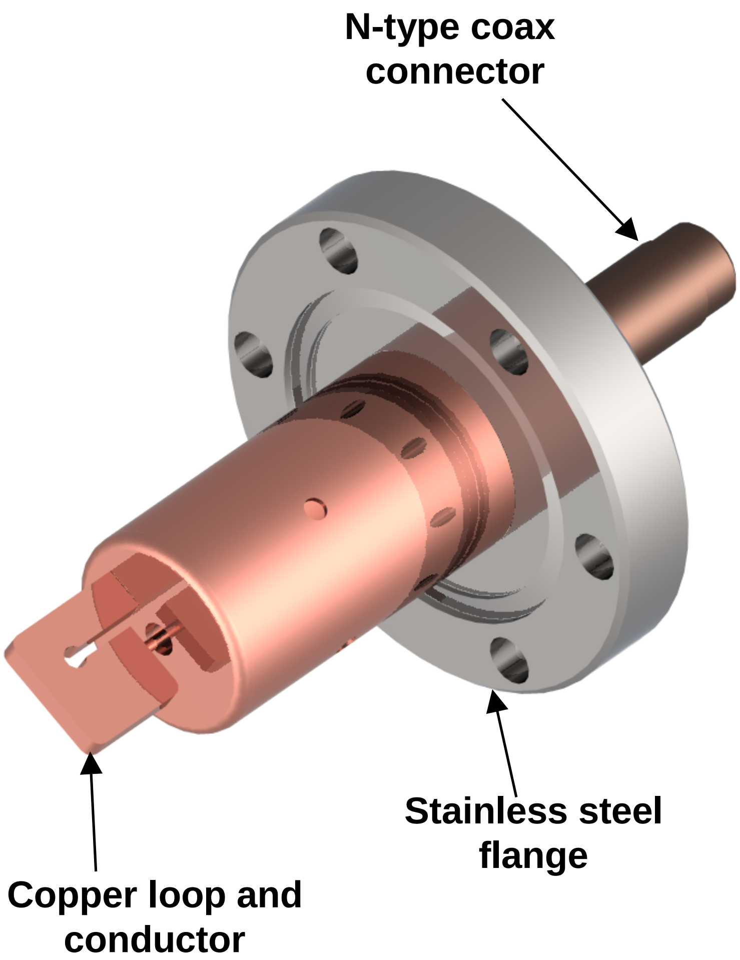
Vacuum Pump Spools

- Provides support for vacuum pumps.
- Bolt on design eliminates welding on tank sections.
- Provides instrumentation ports for the vacuum system.
- Provides easy maintenance and repair.
- Easily adaptable for pump up-grades (if required).
- 304L SST construction with Electro-polished interior.
- Calculated conductance = 846 l/s
- Stress analysis predicts a safety factor of 13 (see "SNS DTL vacuum system PDR report, SNS-104020300-DA0001-R01).



Turbo pump spool shown

Monitor Loop Assembly



- **Provide signals for feedback control.**
- **Provides RF phase and amplitude measurements.**
- **Each tank has 6 monitor loops.**
- **OFE copper and stainless steel brazed construction.**

SNS Drift Tube Linear Accelerator
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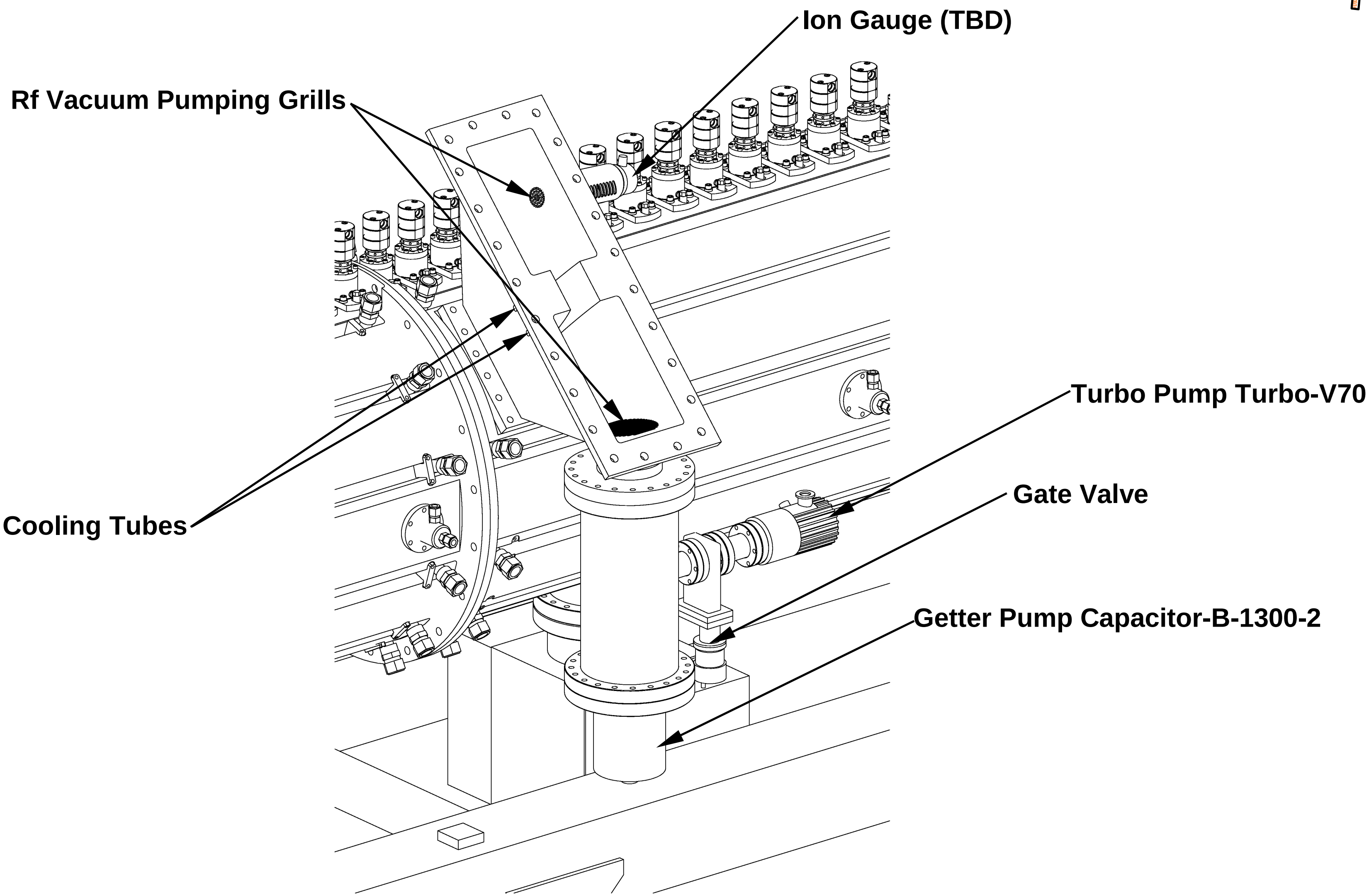
Drift Tube Linac Iris

Richard Lujan

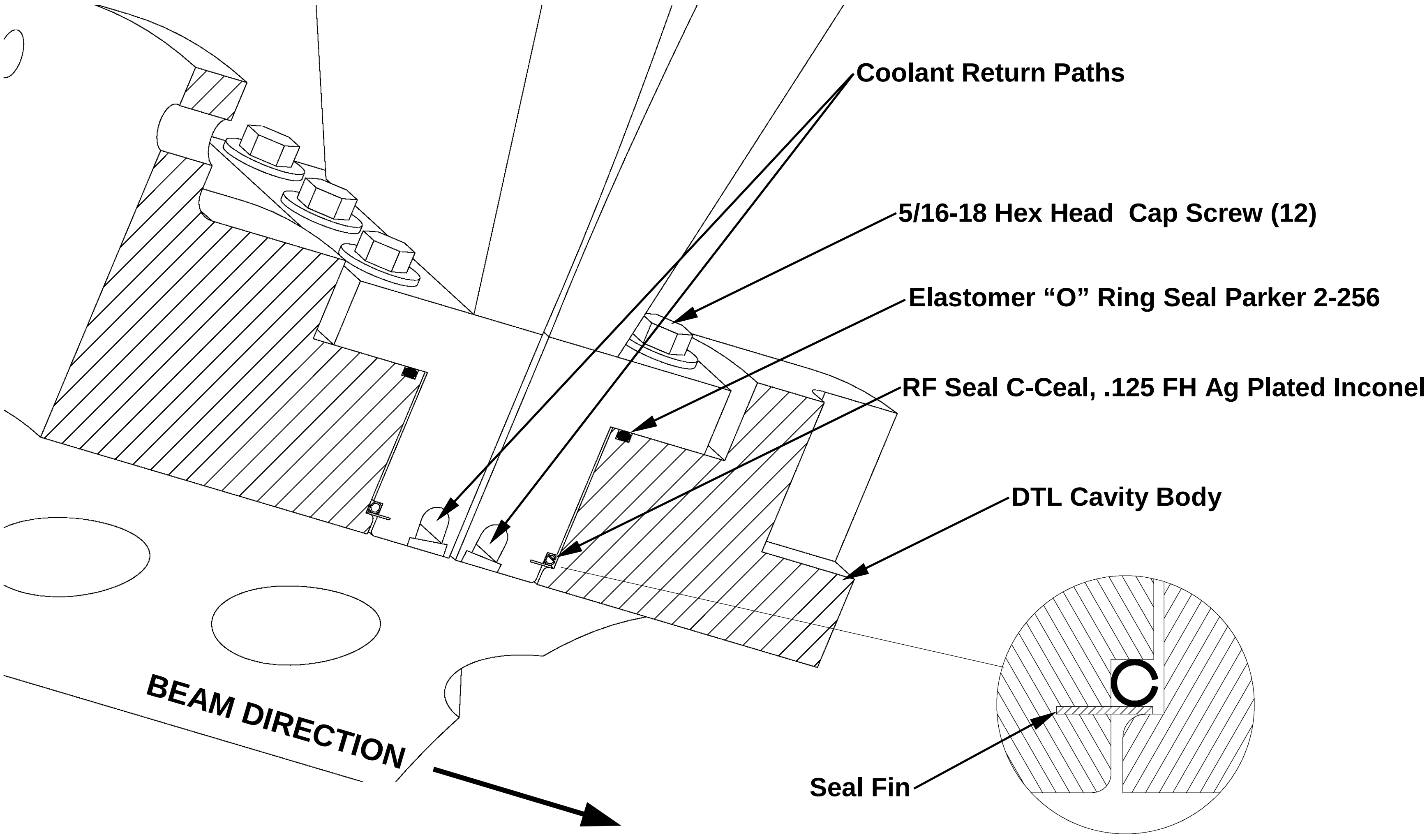
Drift Tube Linac Iris

- Mechanical Design
- Fabrication
- Assembly Considerations

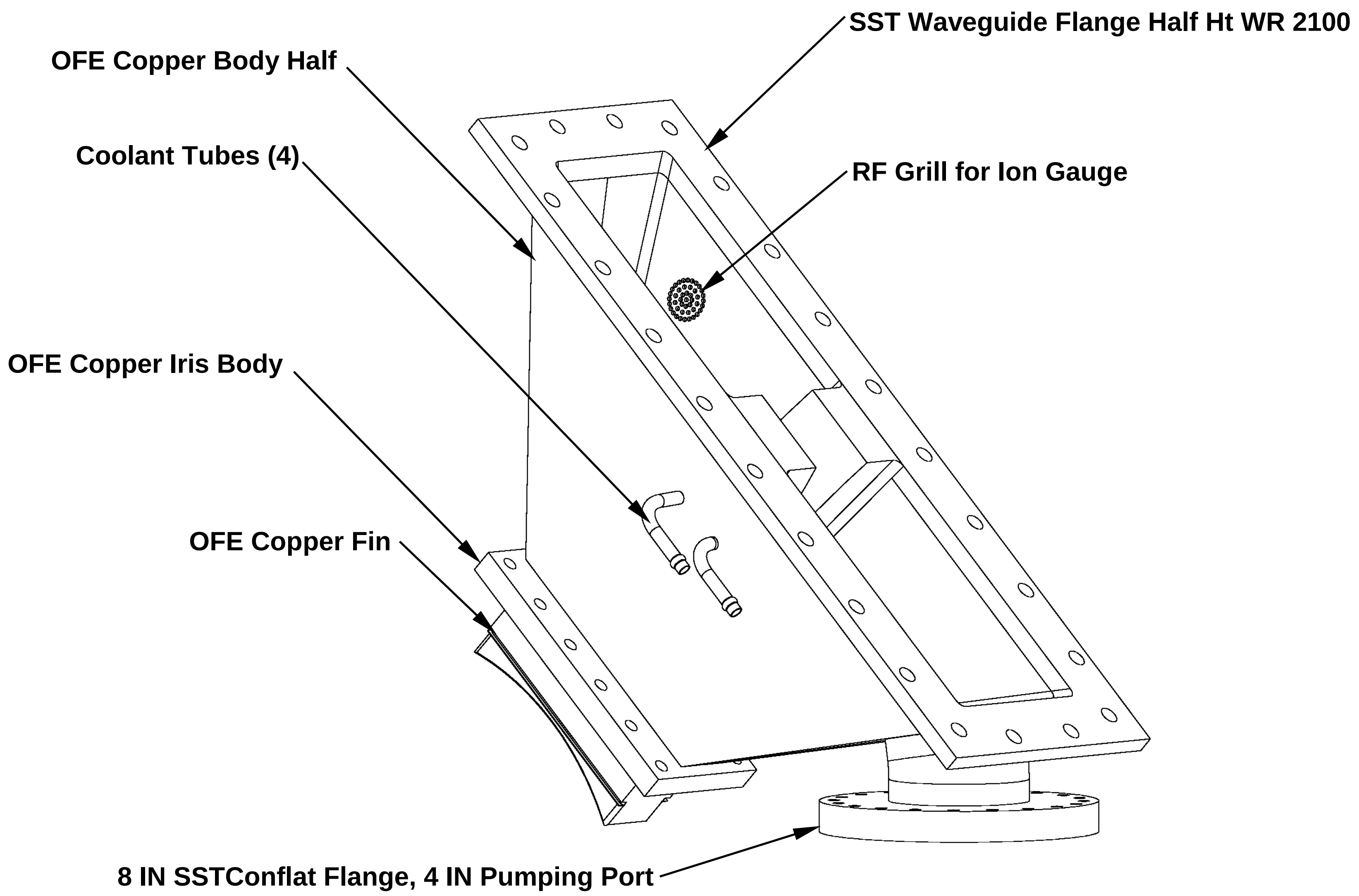
Installed DTL Iris



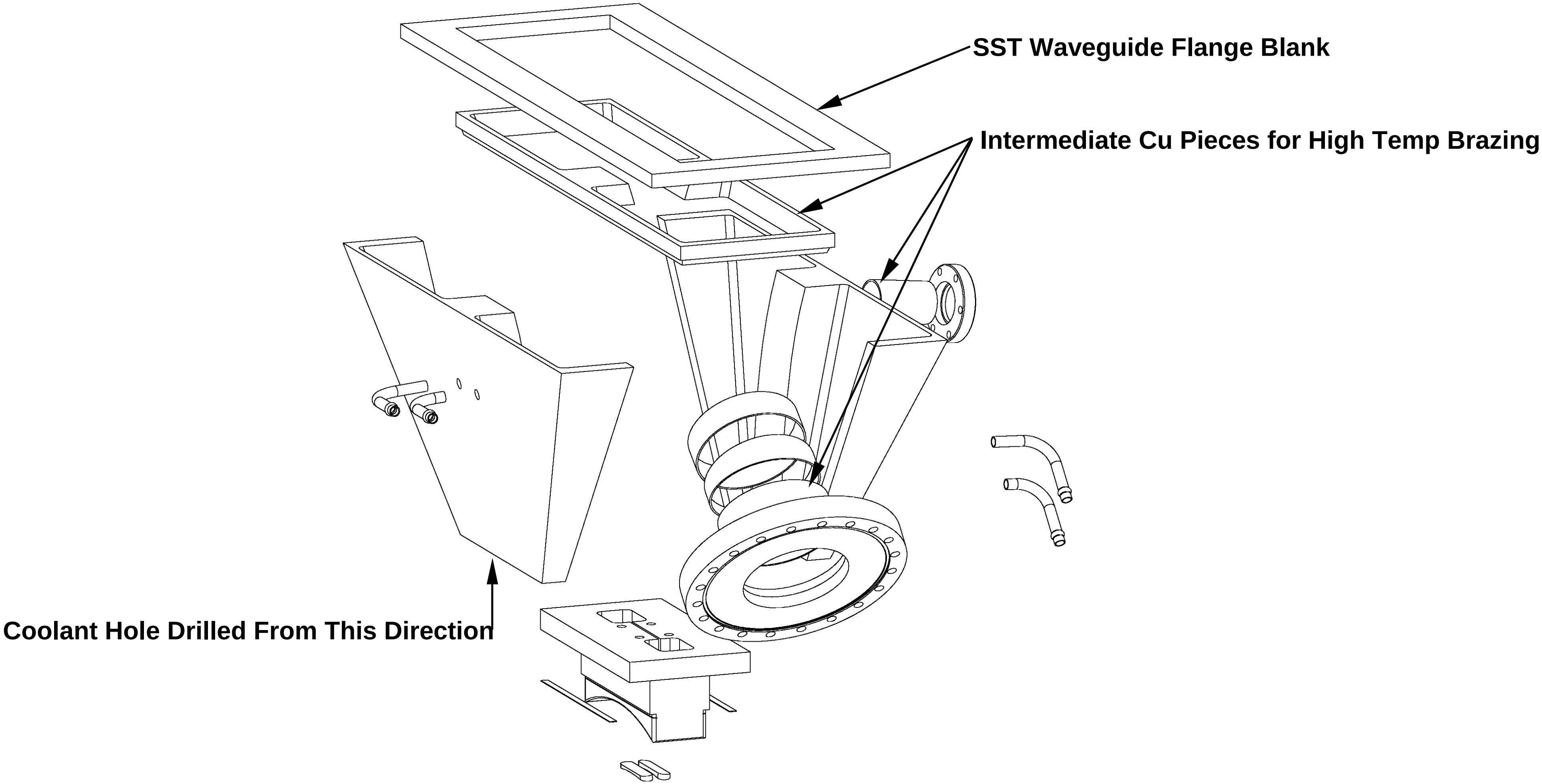
Cross Section Thru Iris



Waveguide/Iris Brazed Assembly



Brazing Parts



Assembly Considerations

- Weight of Brazed Assembly = 100+ LBS
- Mounted at 45 Degrees on DTL
- Assembly Clearances are Small Near the Iris
- Iris Flange Should be “Creatively” Dowel Pinned
- Crane Assisted Assembly Fixtures Will be Needed

SNS Drift Tube Linear Accelerator
Preliminary Design Review
September 26 & 27, 2000

Water Cooling and Vacuum Systems

John D. Bernardin, Ph.D.

Lead Engineer

Presentation Outline

Introduction

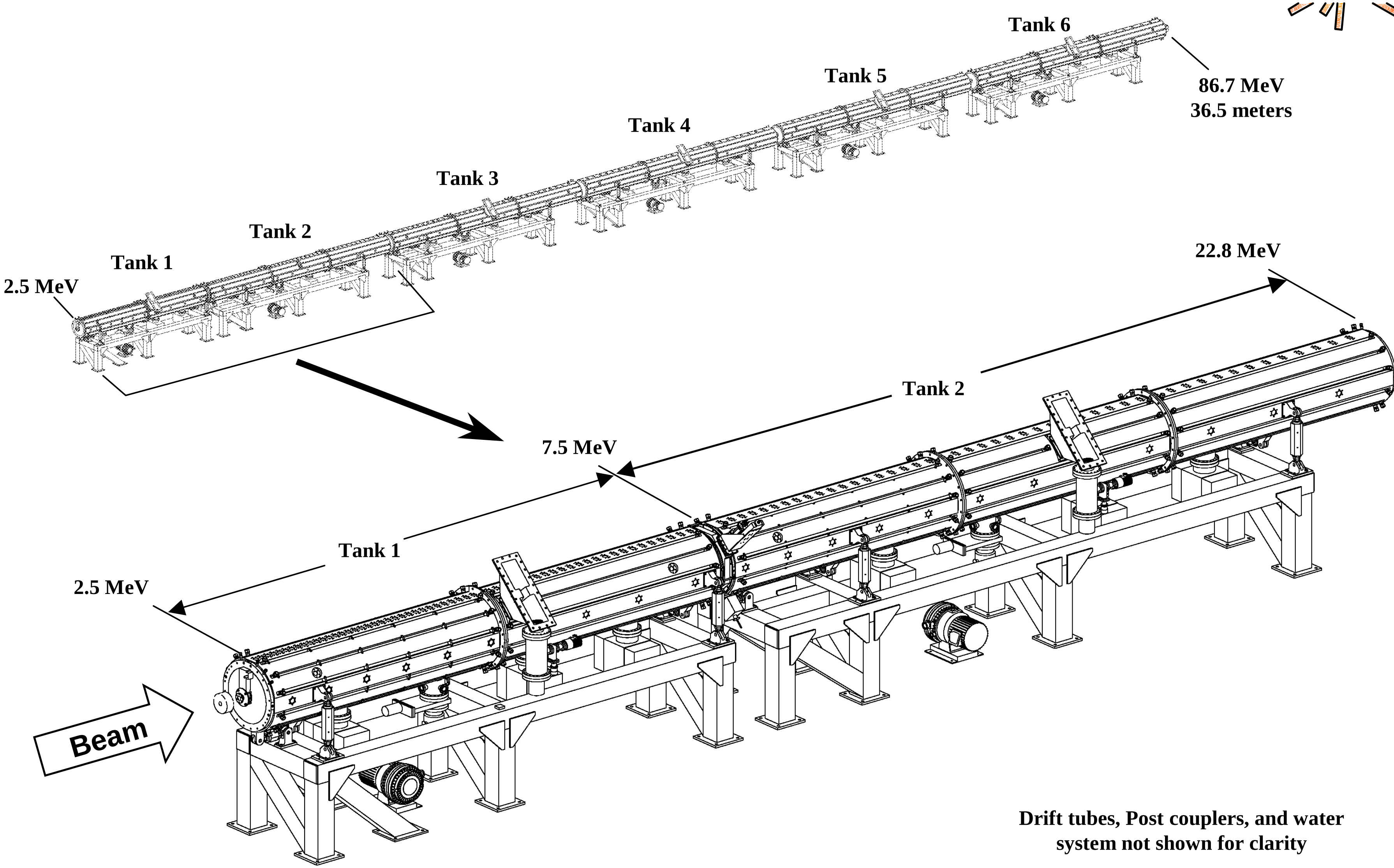
DTL Water Cooling and Resonance Control System

- Design
- Numerical Modeling: Pressure drop, flow, temperature
- Engineering Drawings
- Control System
- Facility Layout
- Hardware Costs

DTL Vacuum System

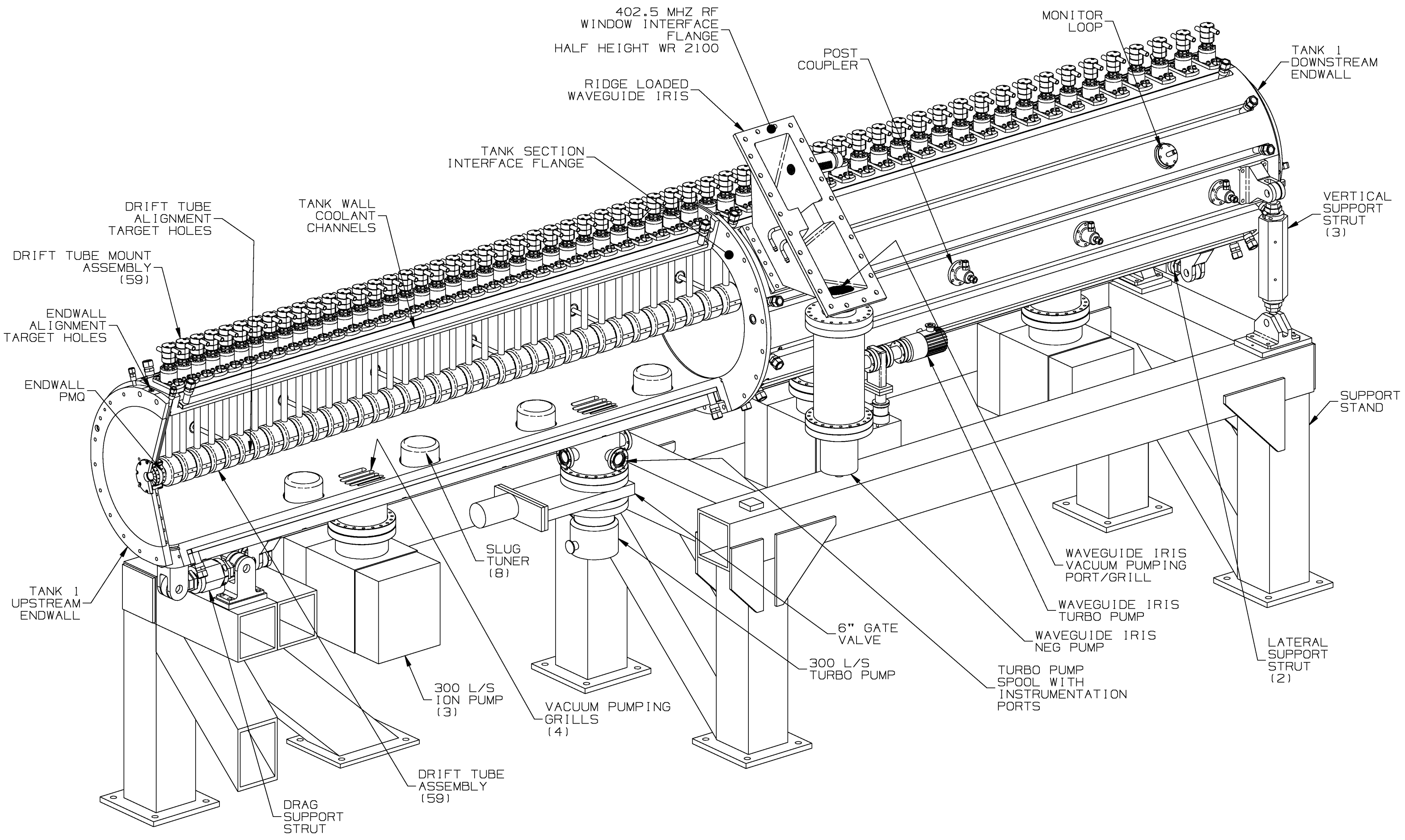
- Numerical Modeling
- Engineering Drawings
- Hardware Costs

Introduction: 86.7 MeV DTL System



Drift tubes, Post couplers, and water system not shown for clarity

Introduction: DTL Tank #1 Assembly



DTL Water Cooling and Resonance Control System

Scope:

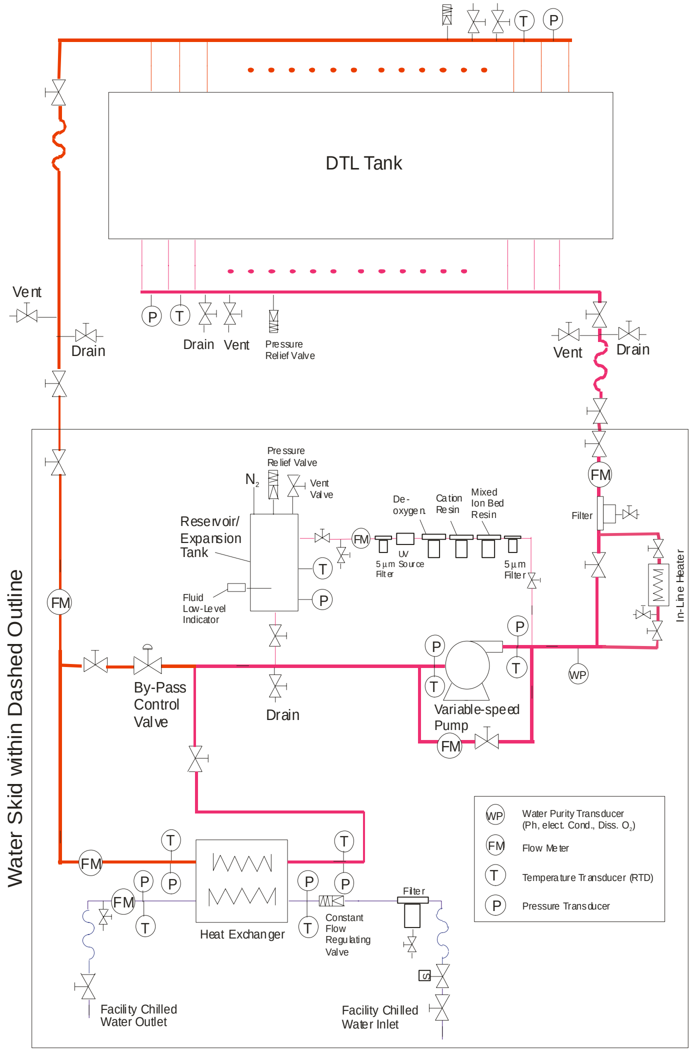
Design, analyze, fabricate, assemble, install and test a robust water cooling system that removes waste heat from the RF structures and magnets, and provides active resonance control of the Linac.

Heat Loads and Flow Rates:

Summary of heat loads and water flow rates for the DTL water pumping stations.

DTL Tank #	Total RF Module Waste Heat Load (kW)	Total Tank Water Flow Rate (gpm)
1	34.2	118.3
2	78.6	160.3
3	90.0	233.8
4	89.9	213.7
5	87.5	197.6
6	91.7	181.6

Design: Closed-Loop Water Cooling System



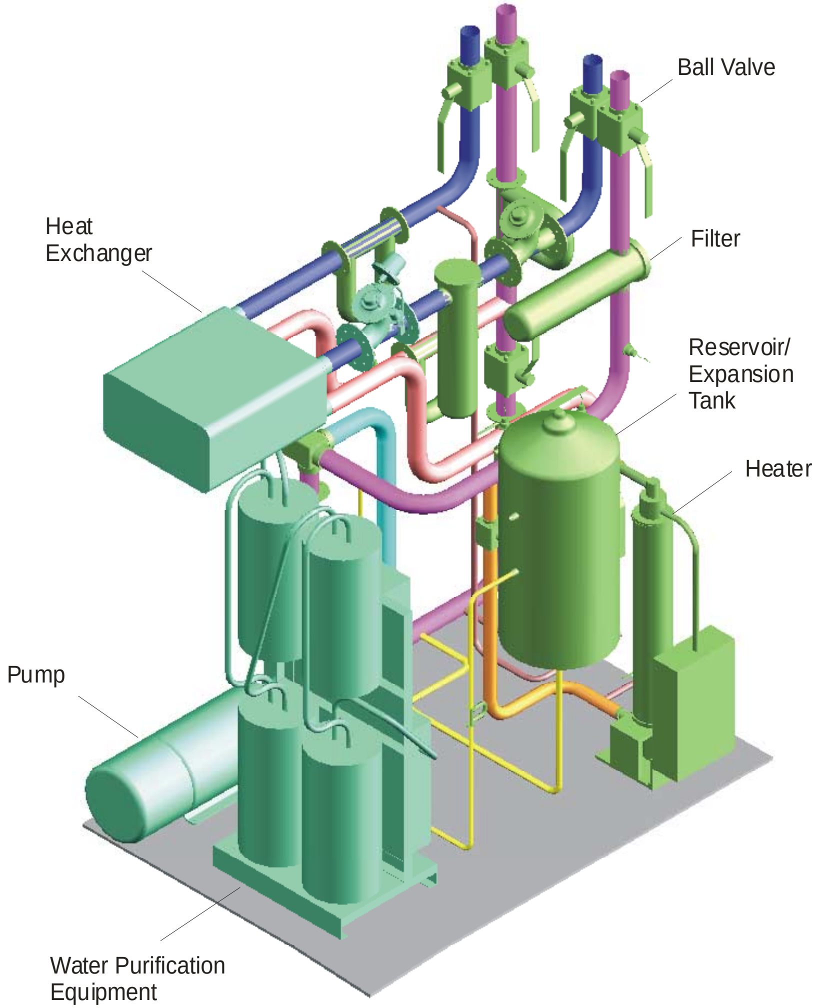
Closed-loop, modular water cooling and resonance control system

<u>Water Skids</u>: 1 water skid per DTL tank to cool drift tubes, tank walls, slug tuners, post couplers, magnets, and iris

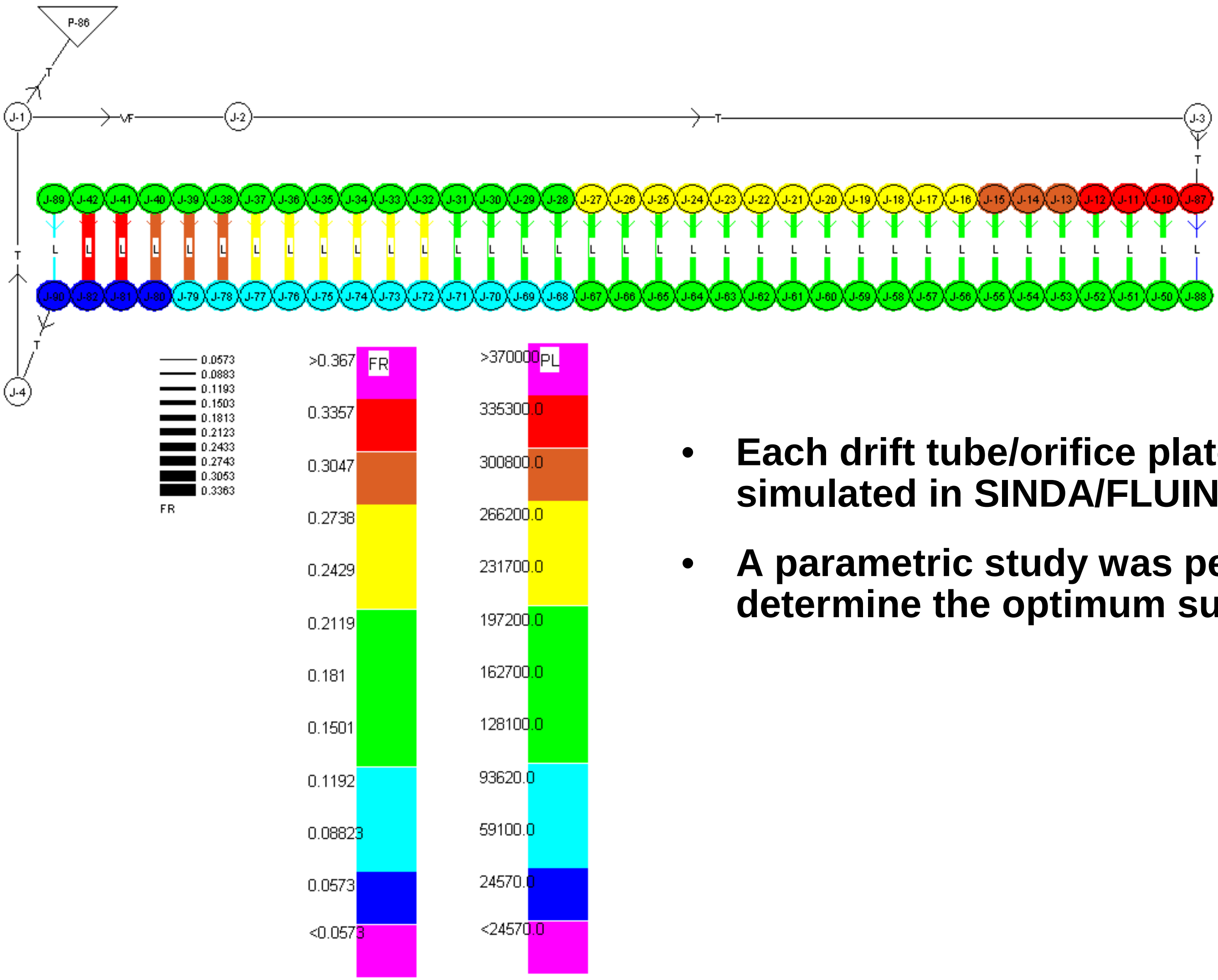
Loops remove waste heat from RF structures and transfer it to facility chilled water via a liquid/liquid heat exchanger

Loops control DTL resonance through temperature control of drift tubes and tank walls (via water temperature control)

Design: Water Skid

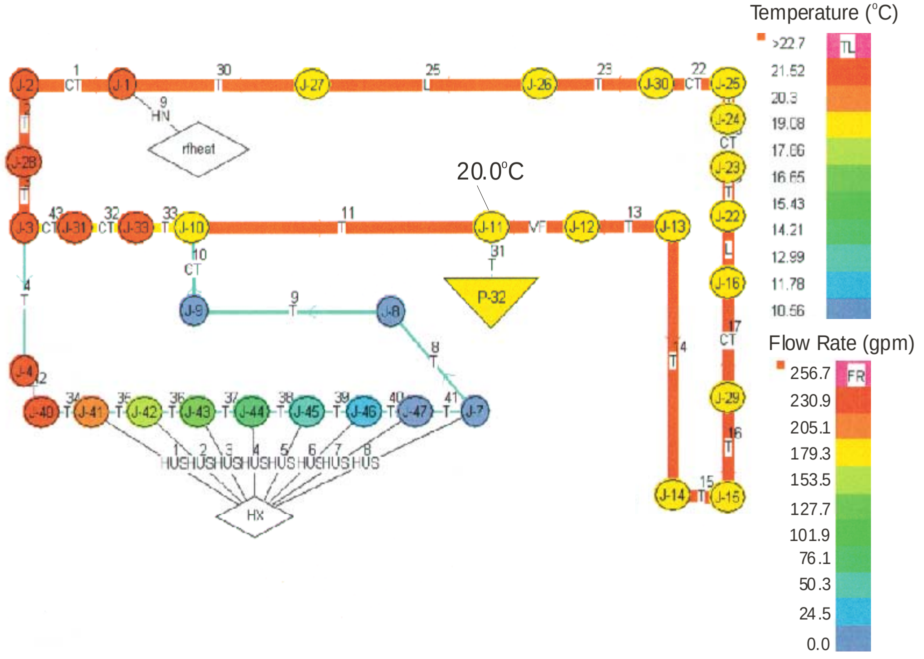


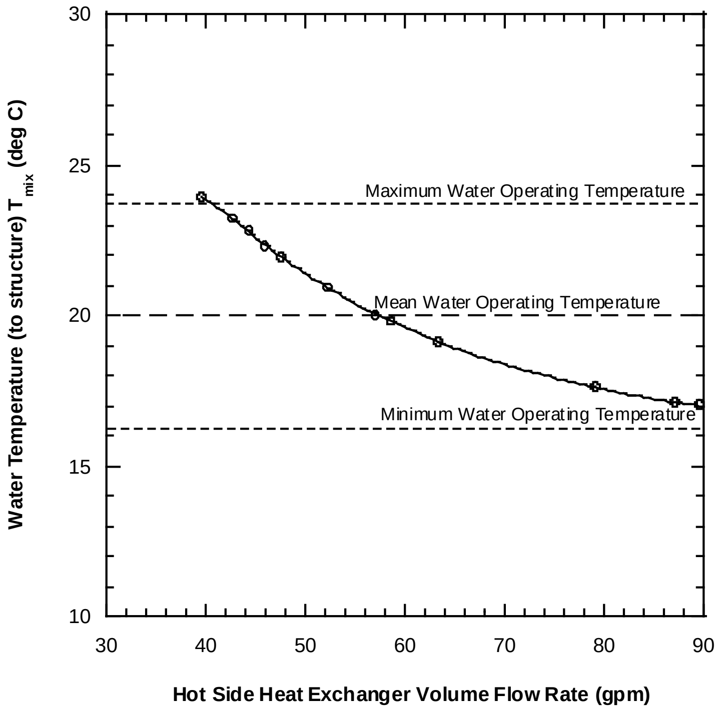
Numerical Modeling: Pressure Drop



- **Each drift tube/orifice plate combination was simulated in SINDA/FLUINT**
- **A parametric study was performed to determine the optimum submanifold diameter**

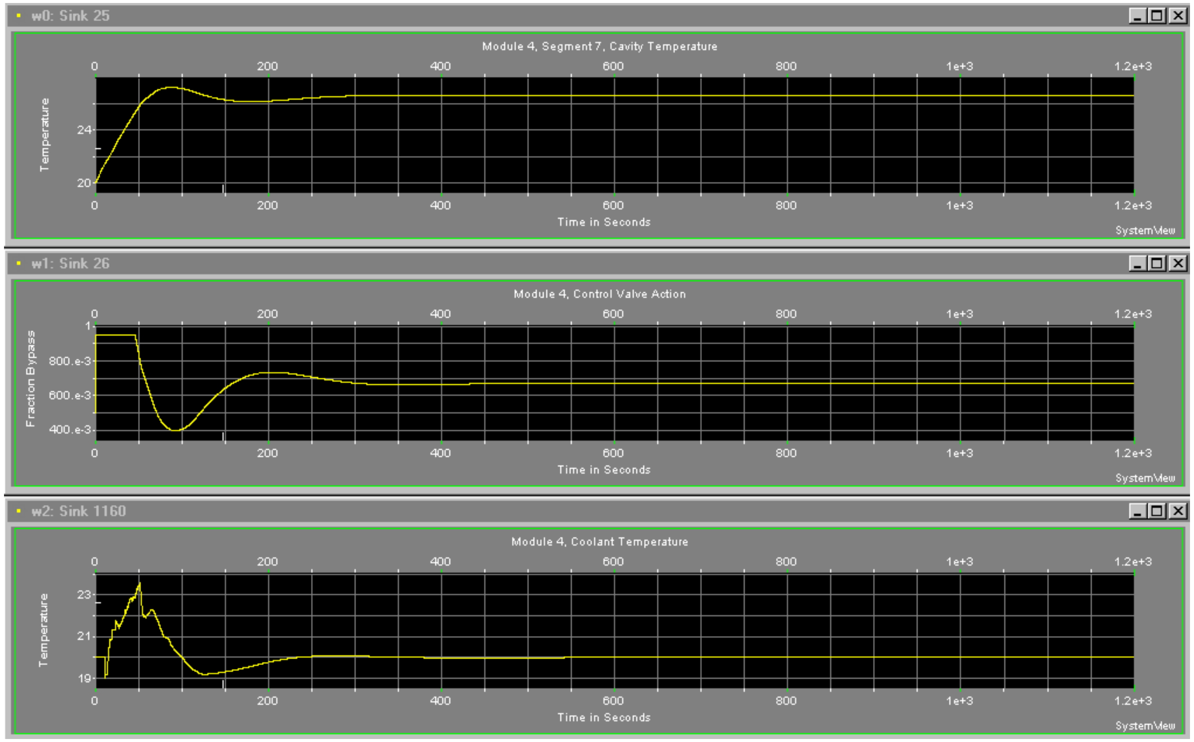
Numerical Modeling:
Steady-State Temperature Distribution





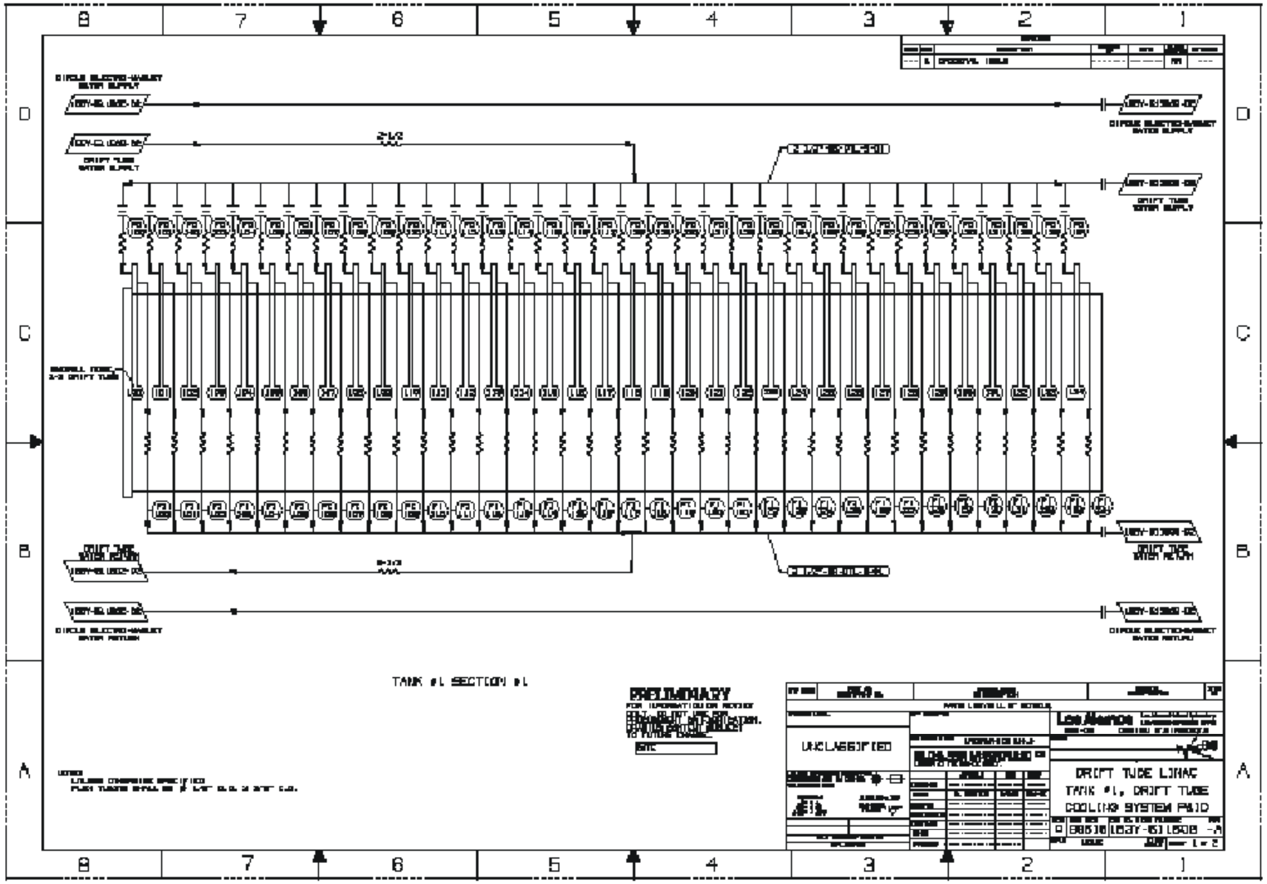
Numerical Modeling: Transient Temperature Response

T_{ci} set to 7.2°C, the setpoint set to 26.6°C and temperature allowed to stabilize

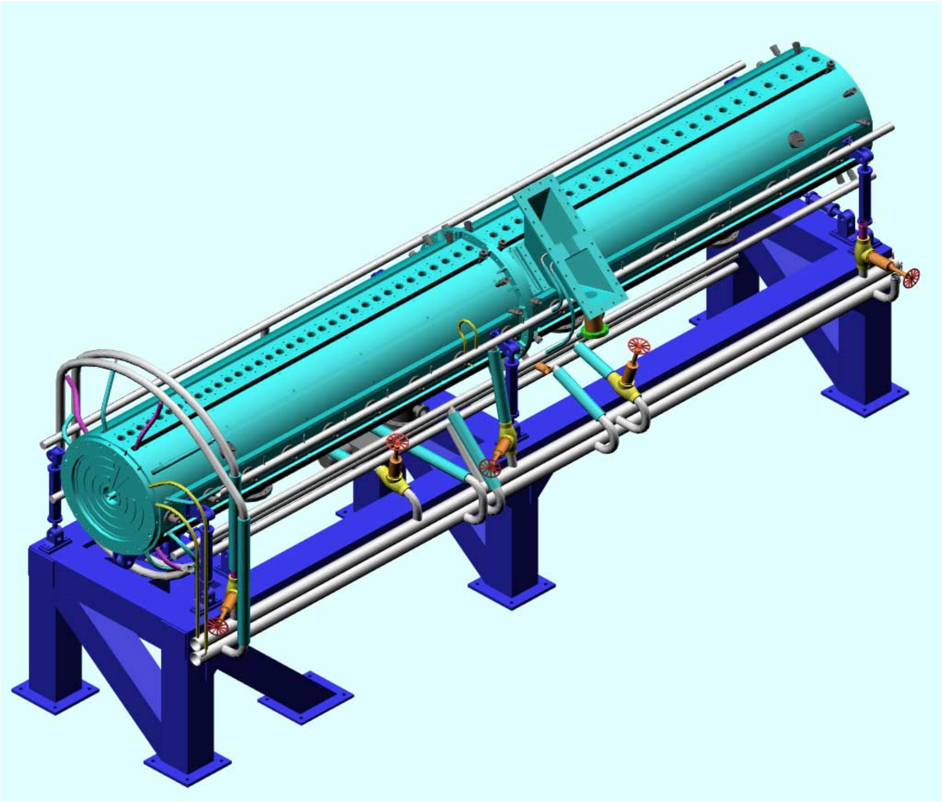


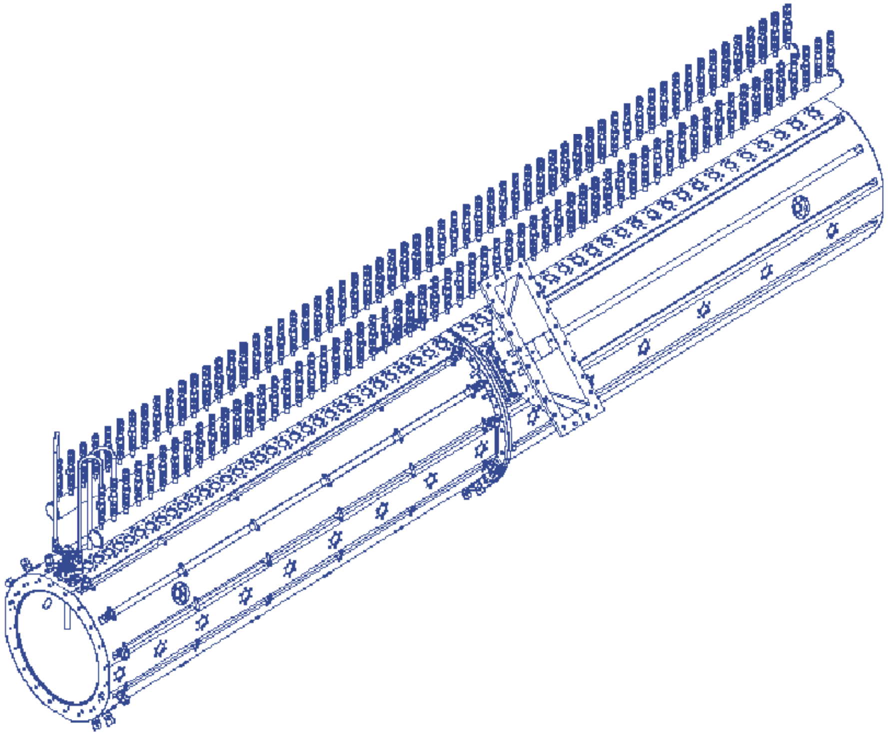
- T_{cav} is 26.6°C, as expected.
- Bypass valve operates at 67% open.
- T_{mix} is 20°C.
- T_{hi} is 22.7°C.
- Stable operation reached at about 300 seconds.

Engineering Drawings: P&IDs

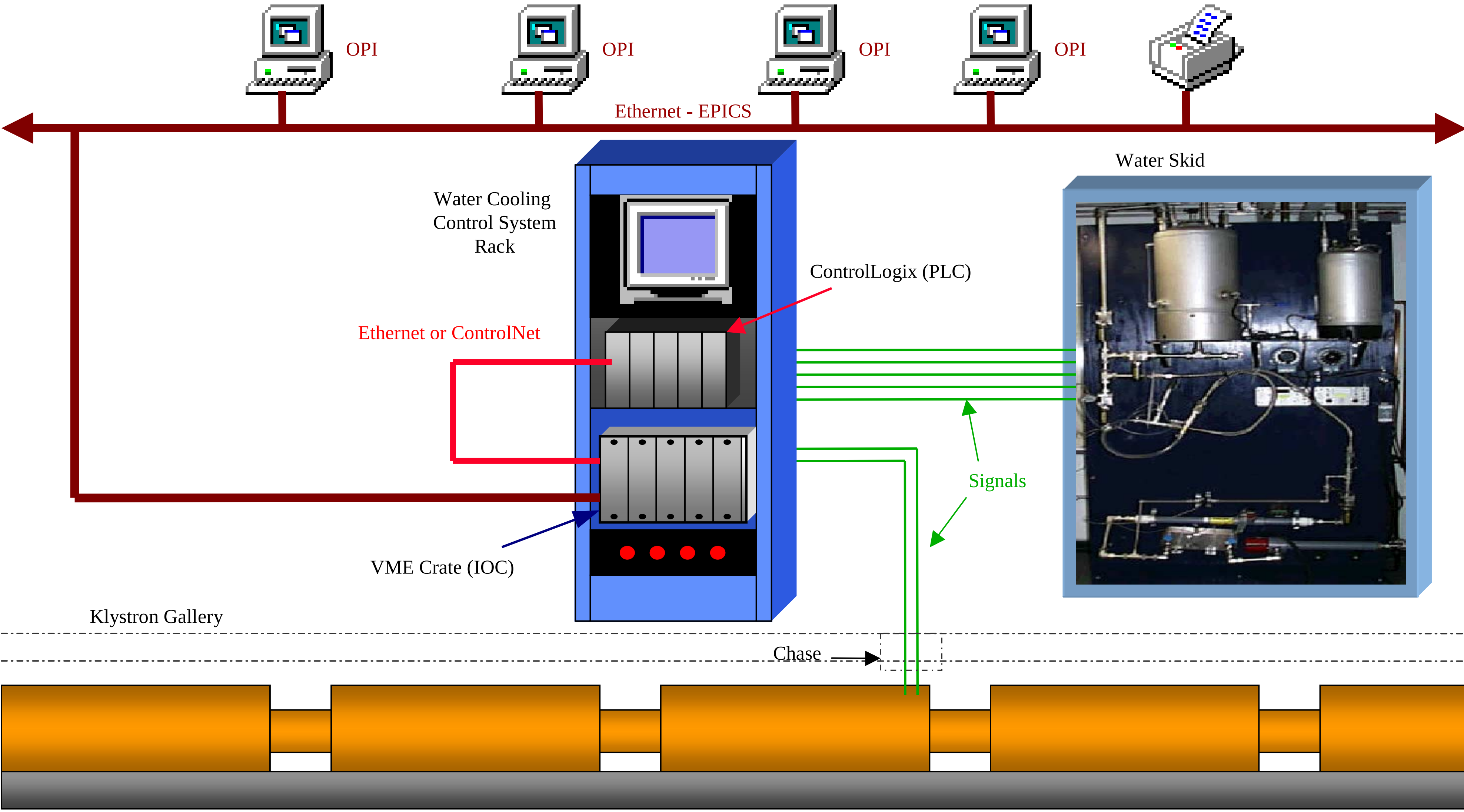


Engineering Drawings: Assemblies

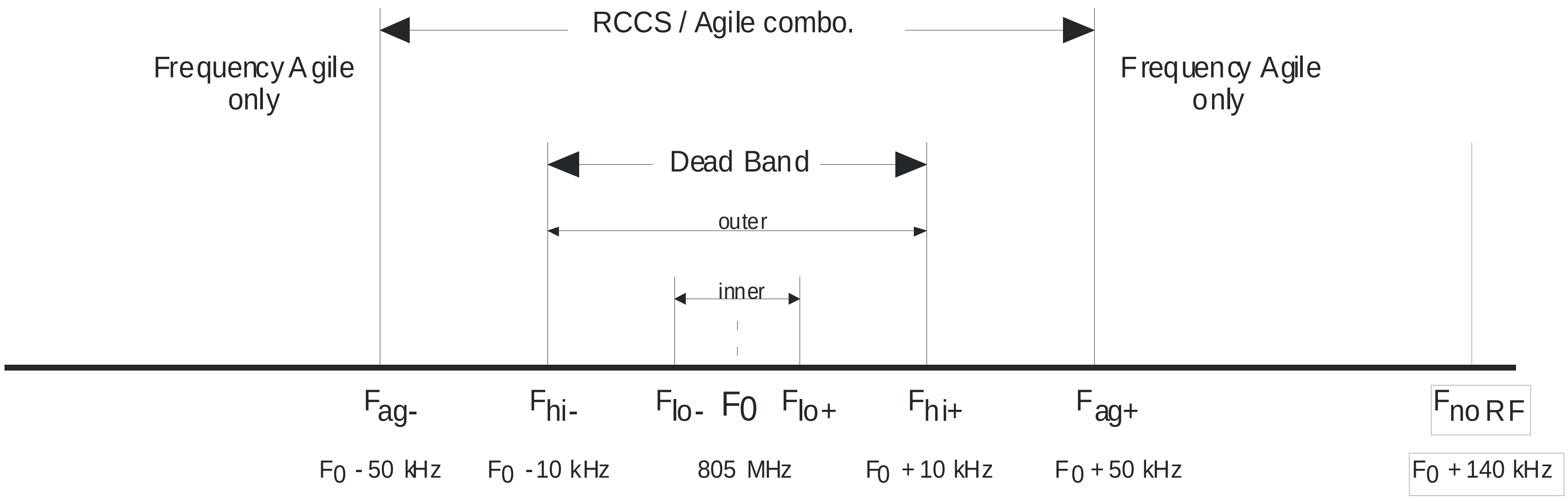




Control System: Architecture

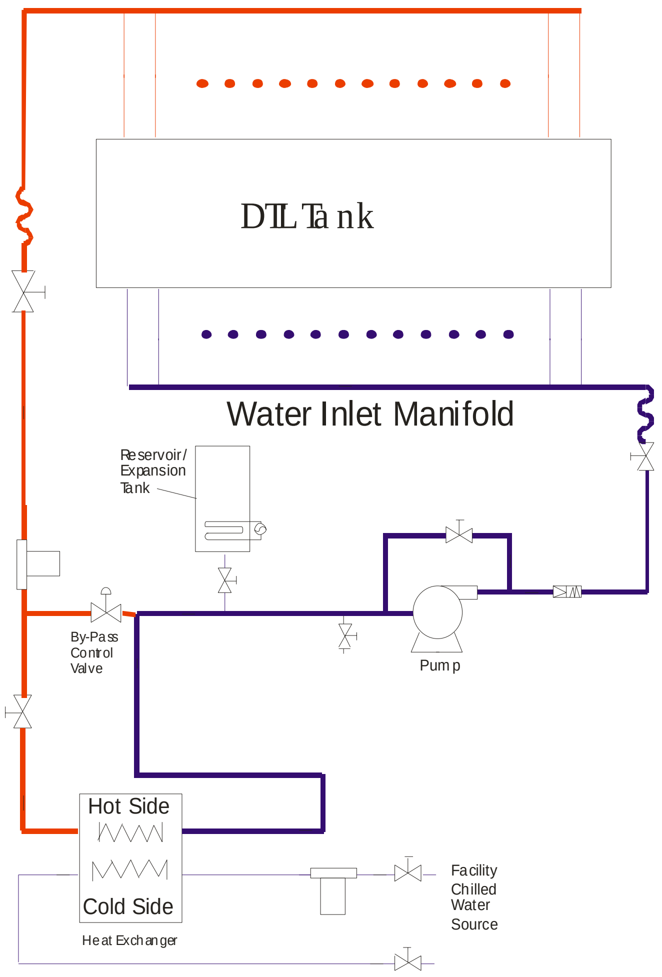


Control System: Resonance Control Philosophy

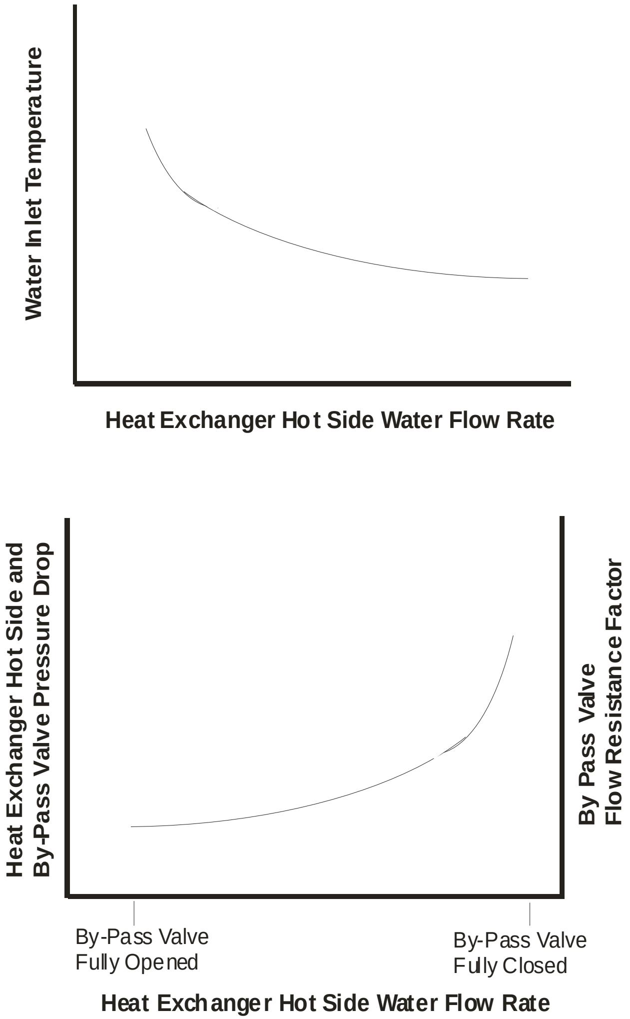


Frequency Agile only:	Water RCCS is inactive, holding at a saturation position of the valves, while the Resonance Control Module brings the drive frequency into the RCCS / Agile band.
RCCS / Agile Band:	RCM and the water RCCS act to control the cavity resonant frequency and bring it into the deadband.
Dead Band:	LLRF control system locks to the fundamental frequency (master oscillator) and the water RCCS takes over to control the cavity resonance within the deadband limits (as determined by operator through the RCM).

Control System:
Resonance Control through Temperature Control

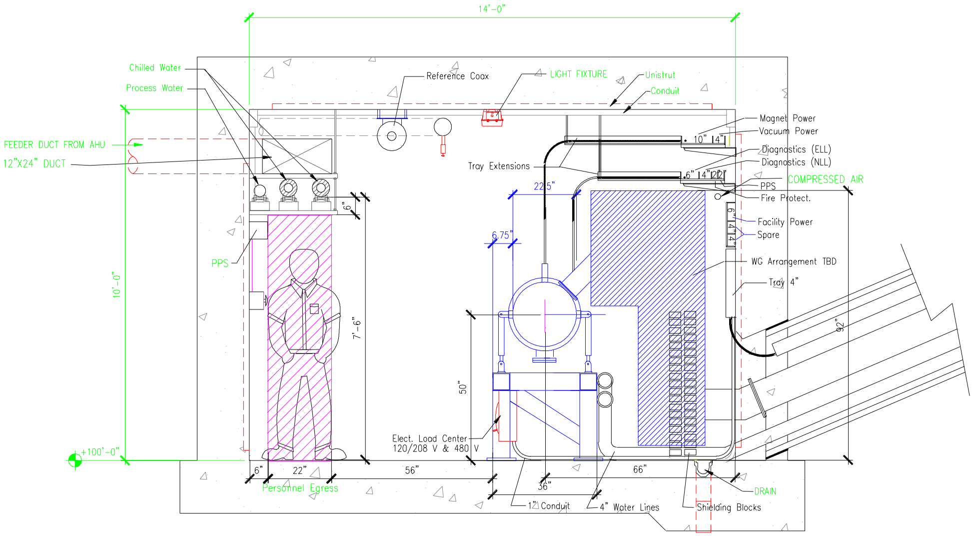


(a)



(b)

Facility Layout and Interfaces



DRAFT

DTL TUNNEL CROSS-SECTION - BASELINE

Sketch No. SK-GAJ-03210-01 Rev 3, 4-26-00

Engineering Issues with A/E

- **Routing of water lines in klystron gallery, chases, and linac tunnel**
- **Positioning of water skids and electronics racks in klystron gallery**
- **50" beam height limits access for installation and maintenance**
- **Junction boxes recommended for instrumentation lines**
- **Electrical and cooling load requirements specified in latest SNS-SRD document.**

DTL Water Cooling System Hardware Costs

Item #	Description	Qty	Supplier	Unit Cost ($)	Extended Cost ($)	Cost Source	Net Cost ($)
1	Drift tube Water skid	6	Parts list	76,627	459764.232	catalog & eng. Judge.	459,764
2	Drift tube Manifolds & Trans. Lines	6	Parts list	32,336	194013	catalog & eng. Judge.	194,013
3	RF struct. Manifolds & Trans. Lines	6	Parts list	43,938	263629.5	catalog & eng. Judge.	263,630
4	PLCs, Computers, software	7	Parts list	$31,500	220500	catalog & eng. Judge.	220,500
5	Electronics rack & equipment	7	Parts list	$1,157	8099	catalog & eng. Judge.	8,099
						GRAND TOTAL	1,146,006

DTL Vacuum System

Scope

Design, analyze, fabricate, assemble, install and test a robust vacuum system (pumps, hardware, instrumentation, controls, etc) that provides a sufficient vacuum for the RF environment and minimizes beam stripping and associated activation.

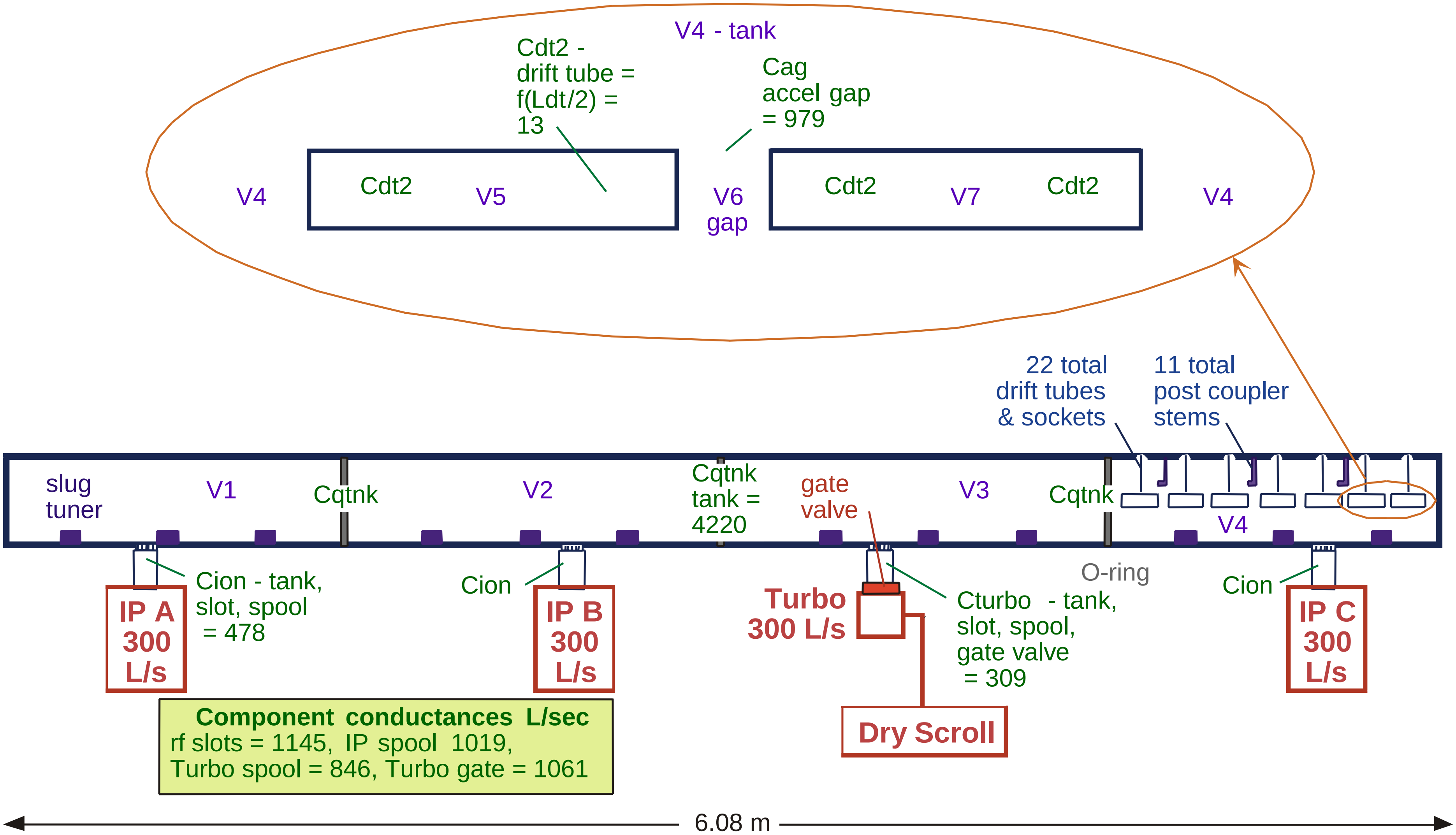
Technical Specifications

$$P_{allowable} = W_{He} P_{He} + W_{H2} P_{H2} + W_{H2O} P_{H2O} + W_{N2} P_{N2} + W_{CO} P_{CO} + W_{O2} P_{O2} + W_{CO2} P_{CO2}$$

- where the weighting factors for the primary gas constituents of interest are as follows: $W_{He} = 0.125$, $W_{H2} = 0.15$, $W_{H2O} = 0.66$, $W_{N2} = 1.0$, $W_{CO} = 1.0$, $W_{O2} = 1.0$, $W_{CO2} = 1.5$

Linac Section	DTL Tank or CCL Module	Exit Beam Energy	Max Allowable Pressure
	No.	MeV	Torr
DTL	1-6	2.5 to 86.8	1.84×10^{-7}
CCL	1	107.2	1.84×10^{-7}
CCL	2	131.1	1.53×10^{-7}
CCL	3	157.2	1.21×10^{-7}
CCL	4	185.6	0.89×10^{-7}

DTL Tank Vacuum Model



Mathematica Vacuum Model Description

GAS LOAD BALANCE

$V_n\, dP_n/dt = \Sigma\, Q_{in} - \Sigma\, Q_{out}$ [Torr-L/sec] for n = 1,N

where Q_{in} = leakage and time-dependent outgassing into volume n

$Q_{out} = C_{nm}\,(P_n - P_m)$ where m is an adjacent volume

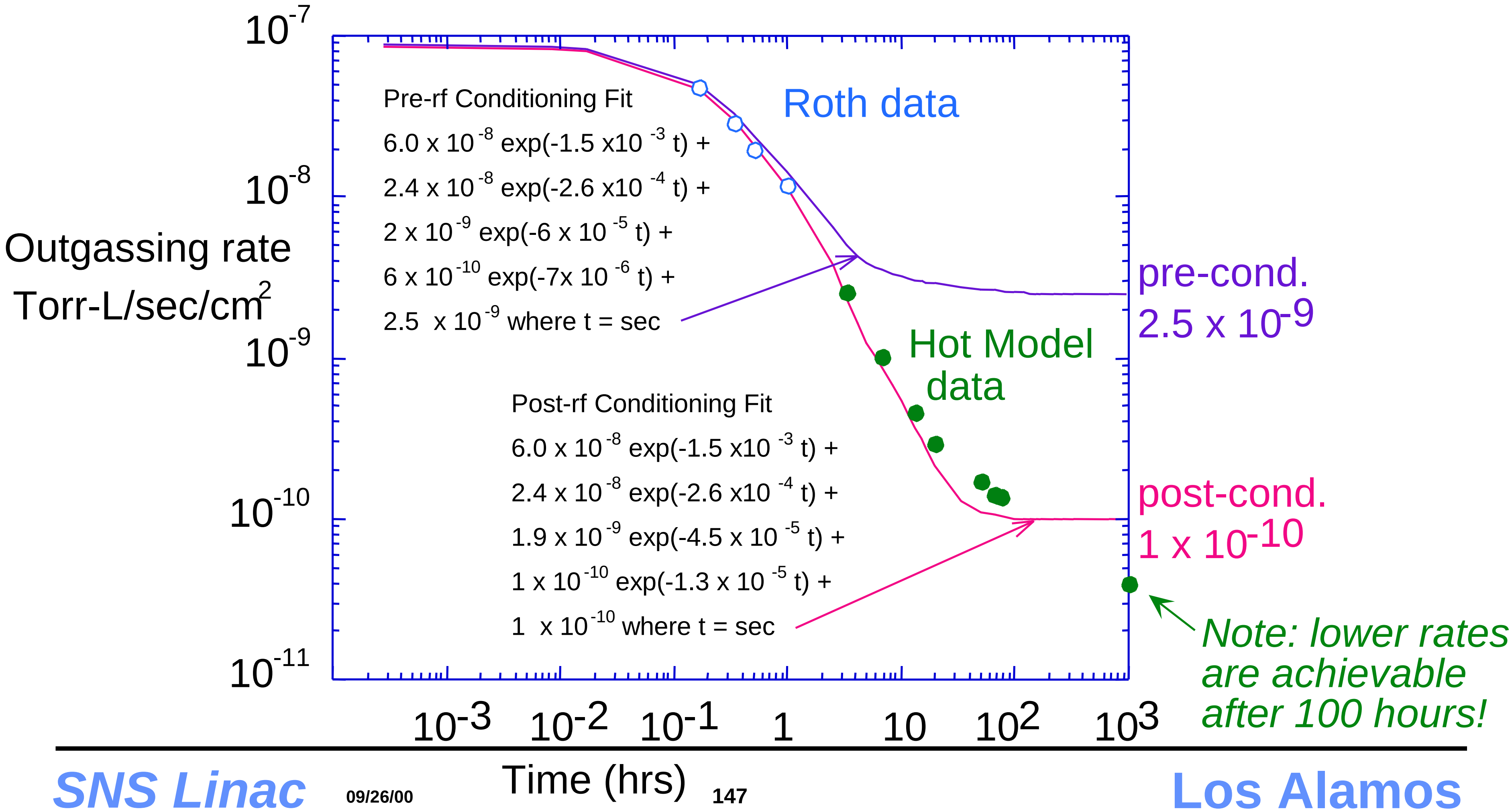
or $Q_{out} = S_p(P_n)\, P_n$

where S_p is pressure-dependent pump speed

- Pressure solved for N sub-volumes
- Pressure-dependent pump speeds
- Solves entire pumpdown history
- Flag for N_2 or H_2 analysis that changes pump speeds and conductances
- Model includes surface outgassing, O-ring permeability and outgassing, and permanent magnet outgassing.
- Separate time-dependent outgassing rates for pre and post-conditioned surfaces

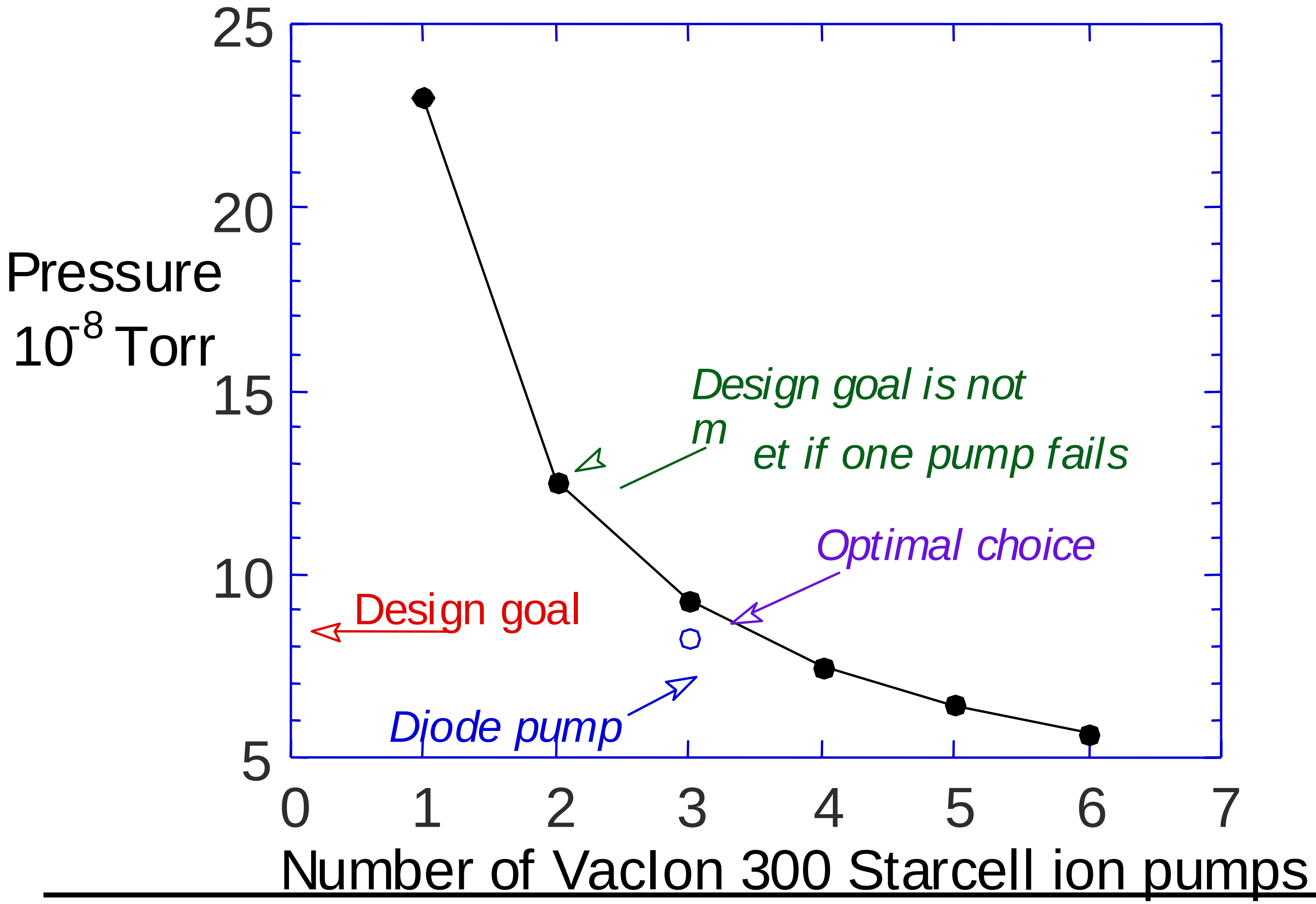
Outgassing Rate for DTL Vacuum Model

Rates based on early data from Roth, from APT Hot Model tests, and final rates specified by SNS management



Vacuum Modeling Results:
DTL Tank Pressure vs. Pump

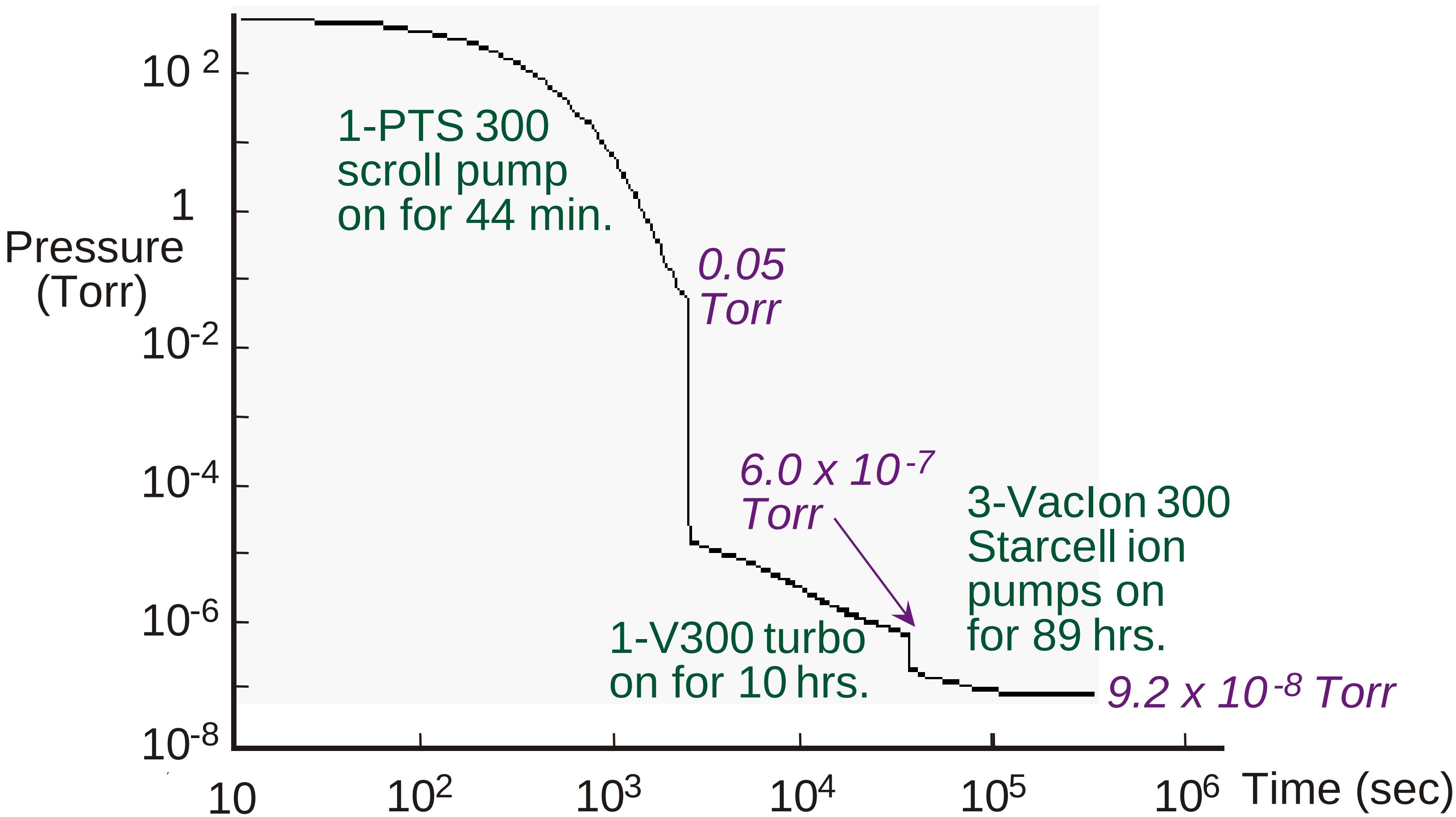
Max drift tube pressure for air after pumping for 100hrs after conditioning (1×10^{-10} Torr-L/sec/cm^2)



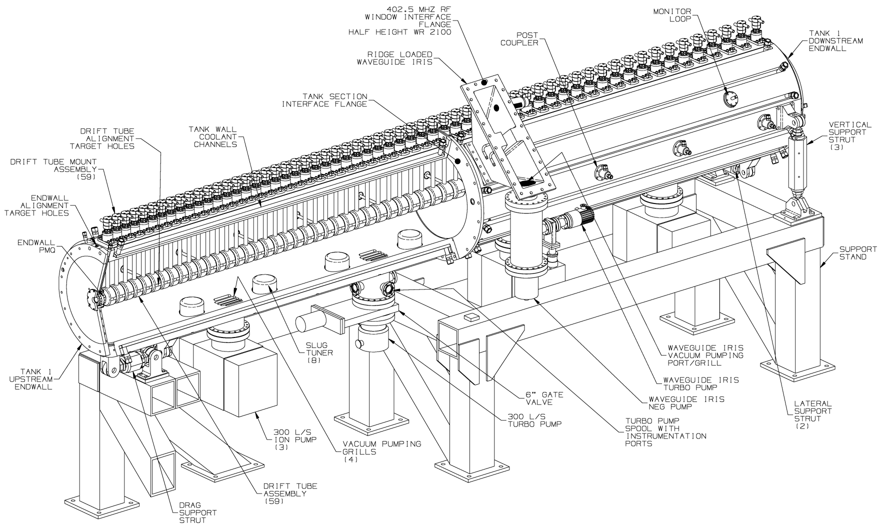
Diode ion pump provides 11% improvement over Starcell ion pump.

Vacuum Modeling Results: Transient Pressure History in DTL

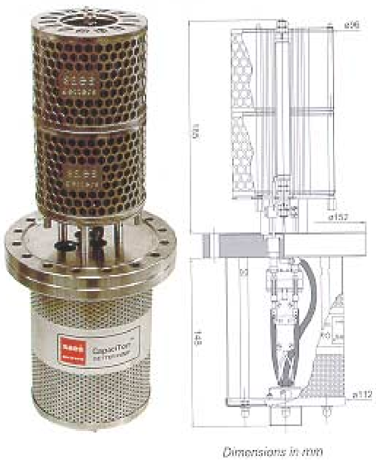
Calculated with the post-conditioned surface rate that has a final value of $1x10^{10}$ Torr-l/s/cm^2



Vacuum Analyses - RF Window



NEG Pump



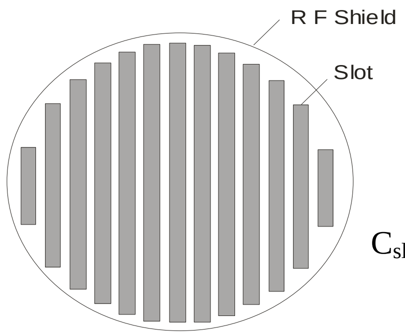
Vacuum Hardware Configuration:

- **One, 1000 L/s NEG pump**
- **One, 70 L/s turbo pump (backed by module roughing pump) with isolation valve**
- **One ion gauge**
- **Equipment ports equipped with RF shields**

NEG Pump Characteristics

- **High pumping speed for its size, especially for hydrogen**
- **Compact, lightweight, no vibration**
- **Must be assisted by small turbo pump for pumping inert gasses as well as activating and conditioning the NEG**

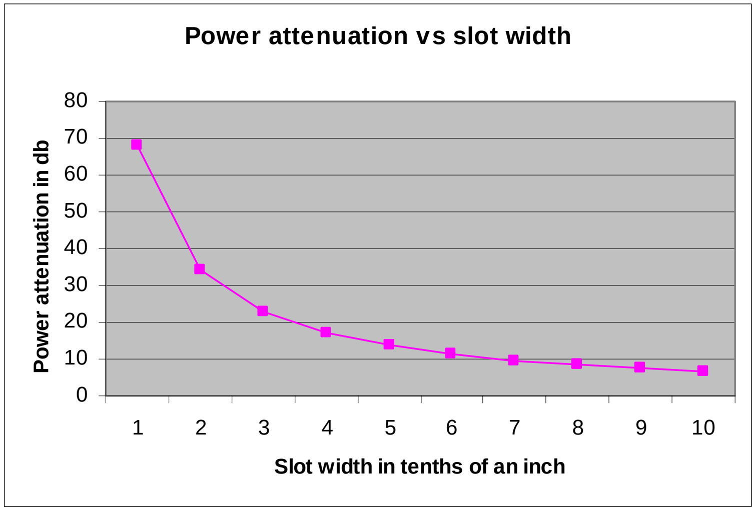
Vacuum Analyses - RF Window cont.



$$C_{slot} = 30.9\, a^2 b^2 K/(a+b)/L$$

$$C_{rfs} = \sum_{i=1}^{13} C_{slot,i}$$

R F Grill Diameter = 6.35 cm (2.5")
Number of Slots = 13
Slot Width = 0.318 cm (0.125")
Slot Depth = 0.635 cm (0.25")
Slot Length = 1.59 cm to 6.03 cm (0.625" to 2.375")
Conductance for air = 404 L/s
Conductance for Hydrogen = 1510 L/s



Pumping Analysis:

$S_{eff} = (Q_w \times A_w + Q_{wg} \times A_{wg})/P_{base}$,

$Q_w = 5\times10^{-8}$ Torr L/s/cm^2 (conditioning)

$A_w = 457$ cm^2

$Q_{wg} = 10^{-10}$ Torr L/s/cm^2

$A_{wg} = 2787$ cm^2

$P_{base} = 10^{-7}$ Torr

$S_{NEG} = S_{eff} \times [C_{rfs}/(C_{rfs} - S_{eff})]$,

Conditioning Pump Speed:

- $S_{NEG} = 542$ L/s

Steady-State Pump Speed

- $S_{NEG} = 27.4$ L/s

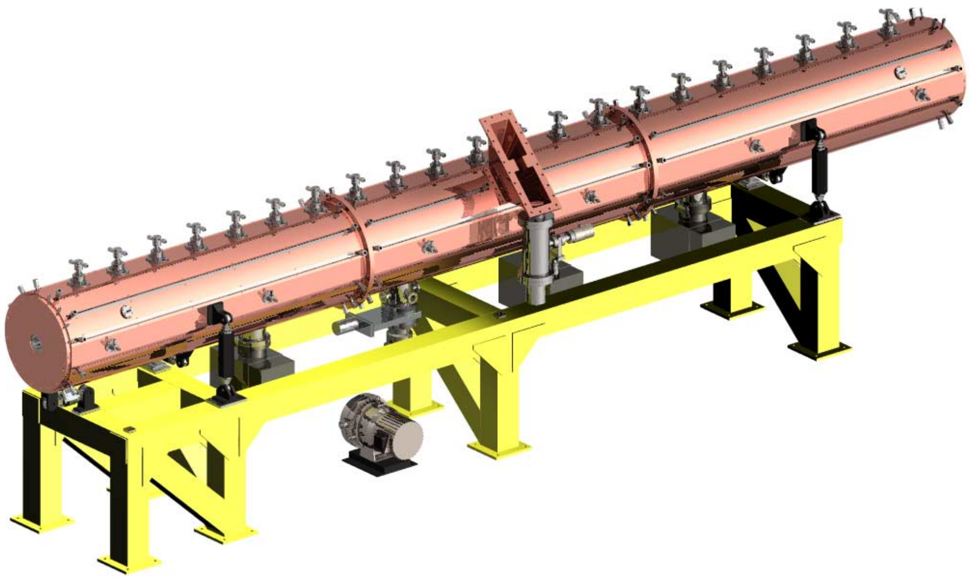
Summary of DTL Vacuum Modeling

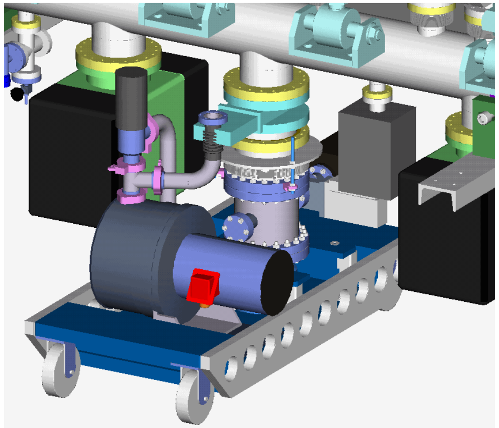
- Our pump configuration meets the design goals by 2X during normal (3 IPs) and failure (2IPs&1T) modes.

SNS Requirements in Torr (either mode)	**Model result for worse case - Tank 6:**
N_2: 1.84 x 10^{-7}	N_2: 9.2 x 10^{-8} (normal)
H_2: 1.29 x 10^{-6}	H_2: 4.1 x 10^{-8} (normal)
	N_2: 8.5 (avg) x 10^{-8} (failure)

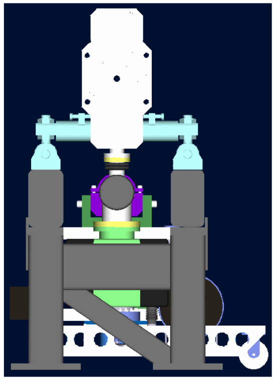
- Cleanliness needed to achieve predicted outgassing rate is critical to reaching predicted pressure! (Final pressure scales with outgassing rate.)
  - The O-ring outgassing rate is 20% of total - we recommend O-ring bakeout prior to installation

Engineering Drawings

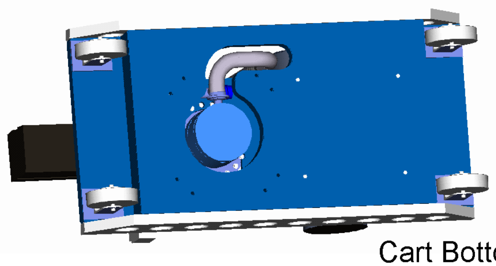




CCL Turbo Cart



Side View



Cart Bottom

DTL Vacuum Hardware Costs

Item #	Qty	Description	Vendor	Part No	Unit Cost	Extended Cost	Qty Disc	Total
1	18	Ion Pump- Valcom Plus 300	Varian	9190700	$ 5,450	98,100	25%	$ 73,575
2	18	Ion Pump Controller, 120 V	Varian	929500	$ 1,800	32,400	25%	$ 24,300
3	18	HV Cables	Varian	9290705	$ 355	6,390	25%	$ 4,793
4	6	Turbo Pump-V300HT	Varian	9699040	$ 7,260	43,560	25%	$ 32,670
5	6	Controller, 120 V	Varian	9699524	$ 2,355	14,130	25%	$ 10,598
6	6	Air-Cooling/Screen	Varian	9699313	$ 435	2,610	25%	$ 1,958
7	6	TriScroll -PTS300	Varian	PTS3001UNIV	$ 5,450	32,700	25%	$ 24,525
8	6	NEG Capacitorr Pumps & Controllers	SAES		$ 9,000	54,000	0%	$ 54,000
9	6	Turbo Pump-V70	Varian	9699360	$ 3,275	19,650	25%	$ 14,738
10	6	Controller, 120 V	Varian	9699505	$ 1,675	10,050	25%	$ 7,538
11	6	Air Cooling/Screen	Varian	9699310	$ 300	1,800	25%	$ 1,350
12	6	Manual All-metal Valve, 6 in	MDC	GV-6000M	$ 2,300	13,800	20%	$ 11,040
13	7	Pnumatic Gate Valve, 1.5 in	MDC	GV-2500M-P	$ 1,500	10,500	20%	$ 8,400
14	6	Stabil Ion Gauge Control unit	Granville Phillips	360101	$ 1,650	9,900	10%	$ 8,910
15	6	Stabil Ion Gauge	Granville Phillips	360120	$ 550	3,300	10%	$ 2,970
16	6	IEEE-488 Computer interface	Granville Phillips	360111	$ 410	2,460	10%	$ 2,214
17	6	Stabil Ion Gauge Cables 25'	Granville Phillips	360114	$ 195	1,170	10%	$ 1,053
18	6	Rack Mount	Granville Phillips	370010	$ 50	300	10%	$ 270
19	6	Dual Convectron Gauge Module	Granville Phillips	360106	$ 395	2,370	10%	$ 2,133
20	6	Six setpoint process control	Granville Phillips	360107	$ 360	2,160	10%	$ 1,944
21	6	Convectron Gauge	Granville Phillips	375238	$ 160	960	10%	$ 864
22	6	Convectron Gauge Cable 25'	Granville Phillips	303031	$ 115	690	10%	$ 621
23	6	RGA, 1-100 AMU	SRS	RGA100	$ 3,750	22,500	0	$ 22,500
24	6	Equipment Rack	Premier Metal	TVA-7019-26	$ 825	4,950	18%	$ 4,059
25	6	Equipment Rack Fan	Premier Metal	PMB-5-150	$ 257	1,542	18%	$ 1,264
26	6	Power Strip	Premier Metal	OB-62-12	$ 75	450	18%	$ 369
27	6	PLC(plus cards,input & output connect)	Allen Bradley		$ 7,231	43,386	0	$ 43,386
28	6	Electrical Hardware(Cables,power supplies)			$ 11,000	66,000	0	$ 66,000
29	6	Valve Interface/Indicator Box			$ 200	1,200	0	$ 1,200
30	1	Local Computer			$ 3,500	3,500	0	$ 3,500
31	1	Software(Labview, PLC, etc.)			$ 4,000	4,000	10%	$ 3,600
32	1	PLC, Cables, Connecters, Motor Starters,etc..			$ 15,000	15,000	0	$ 15,000
33	6	Lot, Misc. Hardware & Gaskets			$ 1,000	6,000	0	$ 6,000
Total								**$ 457,340**

DTL Water and Vacuum Systems Summaries

- **Designs are 50% complete**
- **DTL and CCL Water Systems PDR held Aug. 2, 2000**
- **DTL and CCL Vacuum Systems PDR held June 21, 2000**
- **PDR Review Committees - proceed with final design**
- **Publications:**
  - SNS DTL and CCL Water Cooling and Resonance Control System Tasks and Design Requirements, 104020400-TR0001-R00
  - SNS DTL Water Cooling and Resonance Control System PDR Report, 104020500-DA0001-R01
  - SNS DTL and CCL Vacuum System Tasks and Design Requirements, 104020400-TR0002-R00
  - SNS DTL Vacuum System PDR Report, 104020300-DA0001-R01

SNS Drift Tube Linear Accelerator
Preliminary Design Review
September 26 & 27, 2000

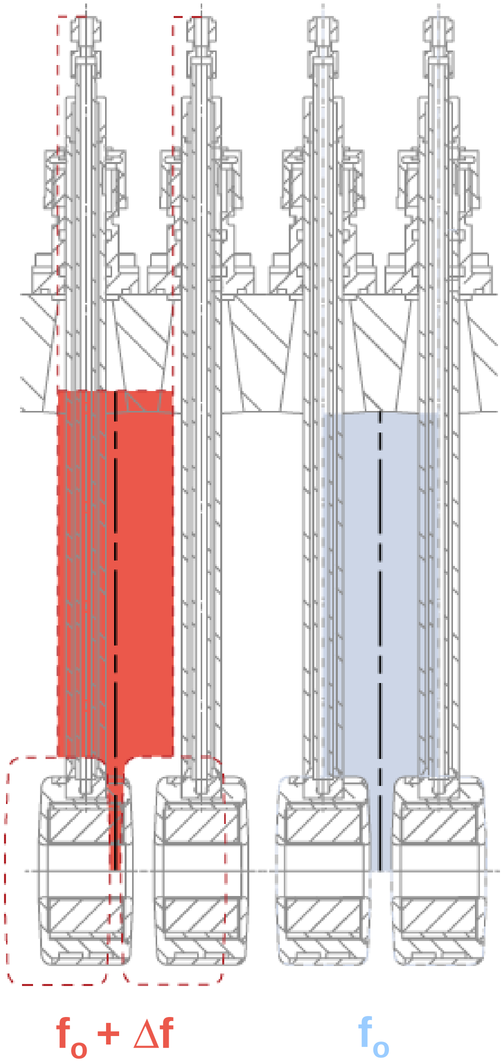
Component Cooling Design and Frequency Shift Studies

Lucie Parietti

Outline

- **Cavity cooling channel design & frequency shift studies**
  - tanks
  - drift tubes
- **Cooling of other components**
  - slug tuners
  - post couplers
- **Testing**
  - thermal coupling of cooling tube to tank wall
  - pressure drop across orifice plate
- **What's next?**

Resonant Frequency Must Be Regulated by Cooling System



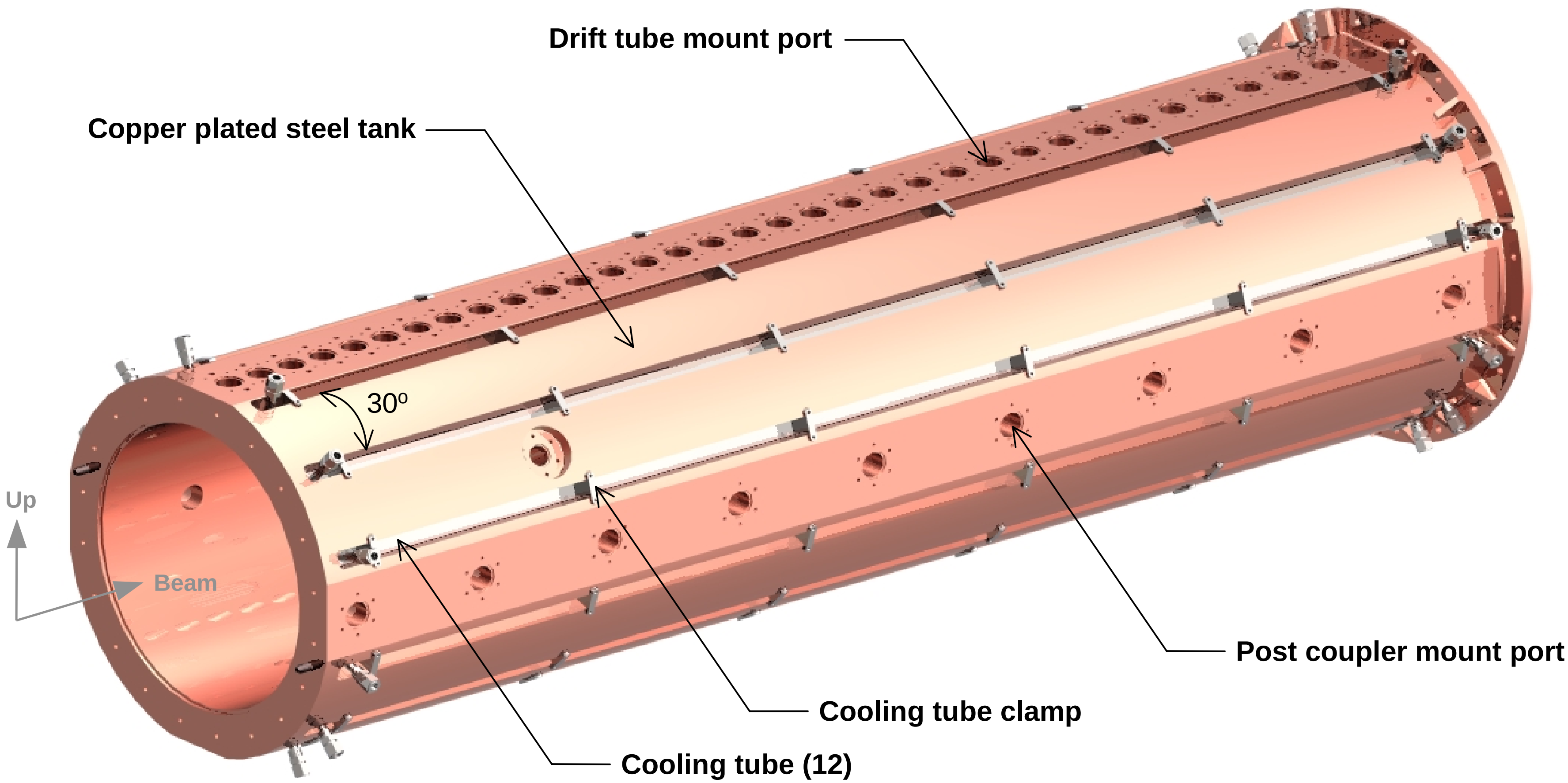
- **80% of RF power dissipates in cavity walls (400 kW - 7% duty factor)**
- **Waste heat causes thermal distortions and resonant frequency shift**
- **System relies on cooling system to compensate for thermal distortions**
- **Frequency shift can be compensated using 3 methods**
  1. Increase flow rate
  2. Decrease temperature of water
  3. Offset cavity frequency by amount equal to frequency shift caused by RF heating

Combination of 2) and 3) is the most efficient way to control RF resonance

Frequency Shift Studies

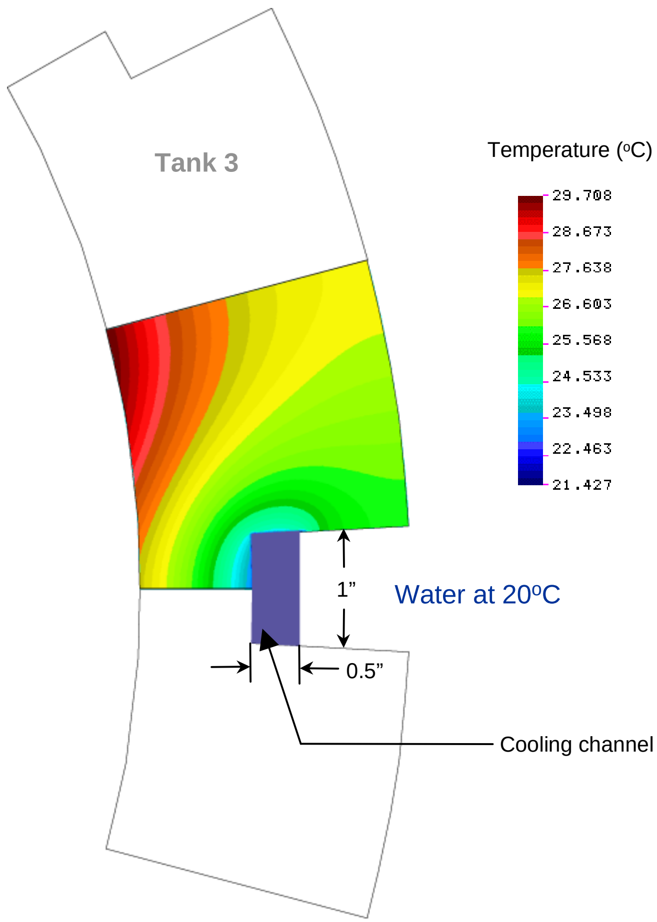
- **Frequency shift studies performed to guide design of cavity cooling passages and resonance control scheme**
- **Size and locations of cooling channels designed to provide adequate cooling and resonant frequency control**
- **Required offset used as primary technique to control resonance is evaluated based on frequency shift**
- **To evaluate frequency shift**
  - Temperature distributions and thermal deformations evaluated separately for tank and 18 drift tubes (3 per tank) using FE models
  - Frequency shift of 18 cells computed based on calculated deformations (Slater theory)

DTL Tank



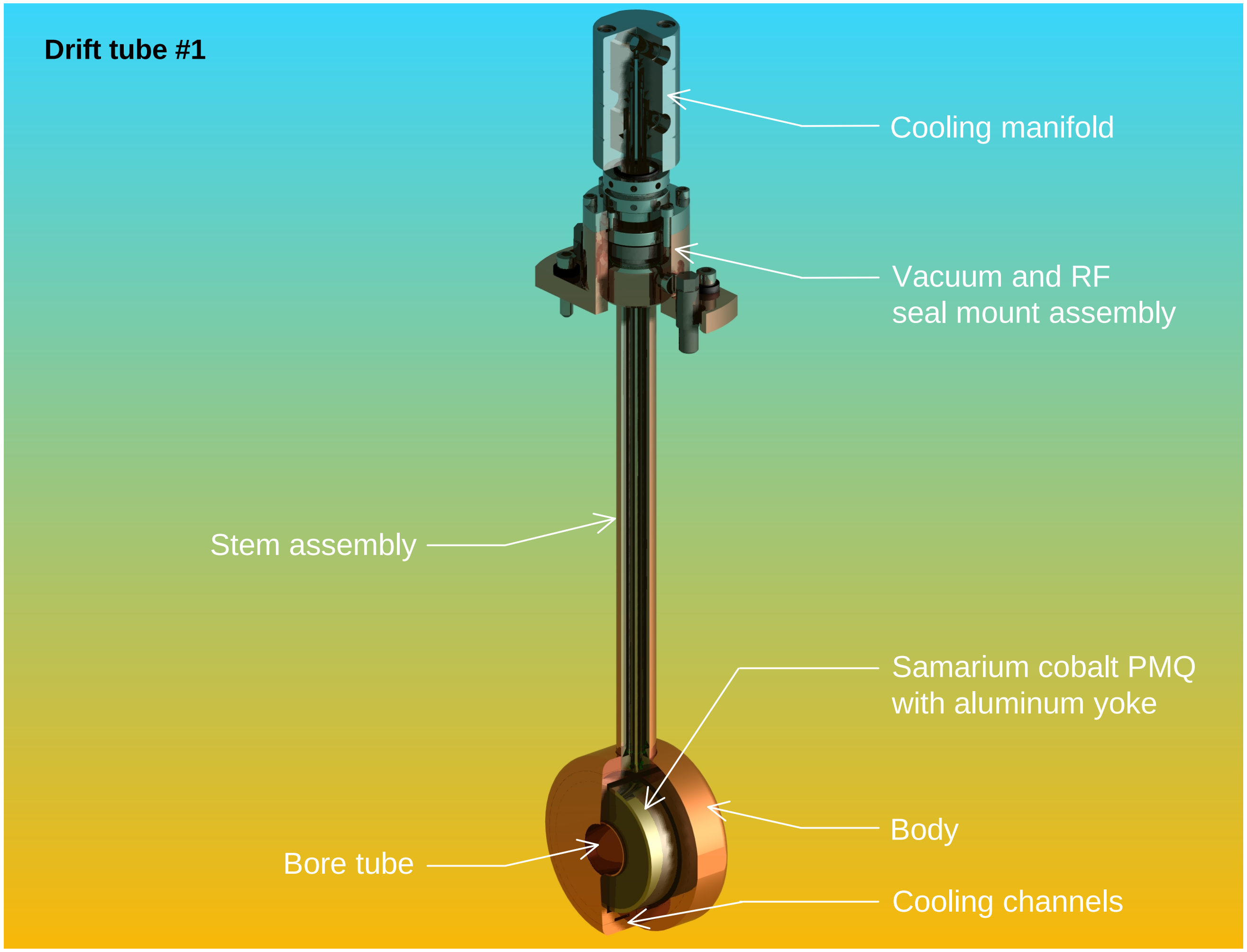
Drift tube mount port
Copper plated steel tank
30°
Up
Beam
Post coupler mount port
Cooling tube clamp
Cooling tube (12)

DTL Tank Temperature Distribution

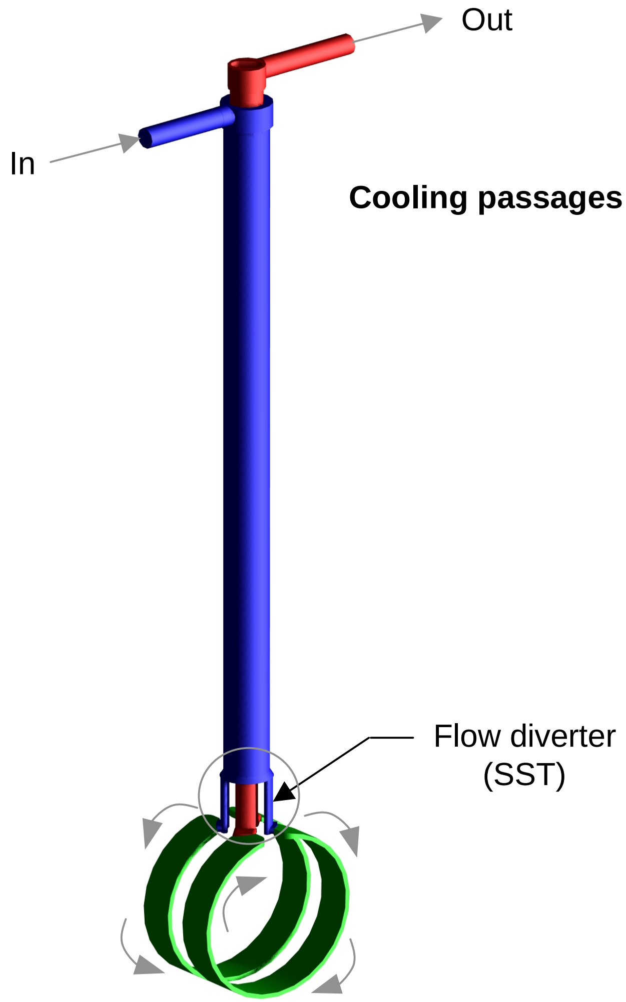


- **12 rectangular SST channels clamped in grooves machined in tank walls**
- **Heat load on inside wall from SUPERFISH (5% safety margin)**
- **Water velocity and flow rate,**
  - 0.5 m/s in tank 1, 19 gpm
  - 1.5 m/s in tank 2, 60 gpm
  - 2 m/s in tanks 3 through 6, 79 gpm
- **Water temperature rise, 2^{o}C**
- **Heat transfer coefficient applied on edges of cooling channels simulates forced convection boundary condition**
- **Contact resistance accounts for imperfect contact between tank and cooling tube**

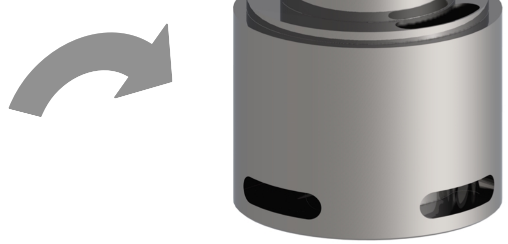
DTL Drift Tube



Drift Tube Cooling Design



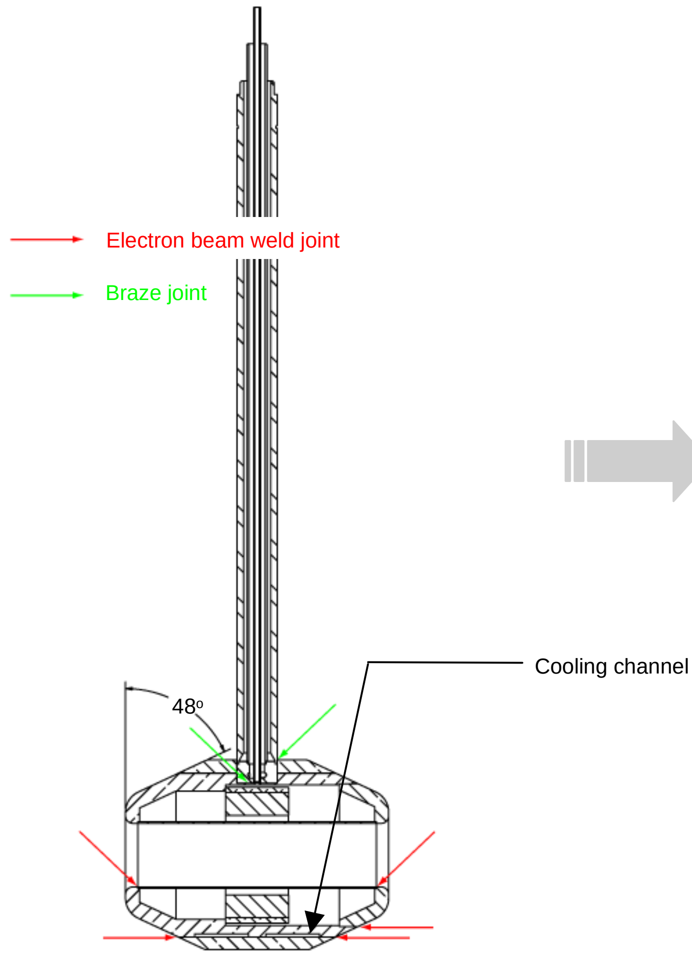
- **Flow through copper channels < 2.5 m/s**
- **Flow turns in SST flow diverter**
- **4 stem designs to accommodate different drift tubes (PMQ, EMD, BPM)**
  - tanks 1-2, 3/4" for PMQs and 1" with oval tube for EMDs
  - tanks 3-6, $1^{1/4}$" (+ oval tube for EMDs)



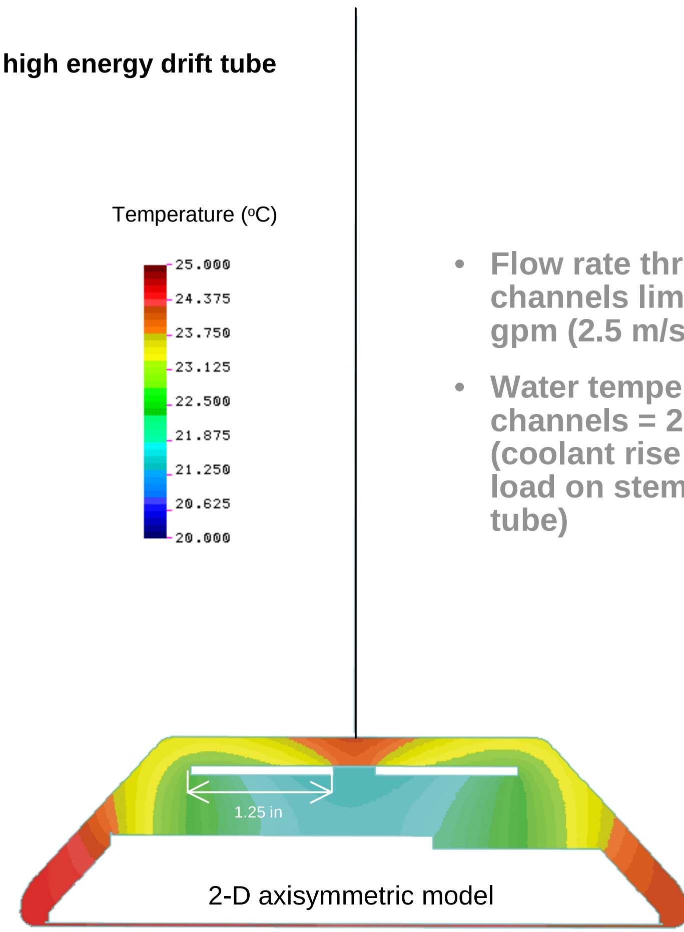
PMQ
flow diverter

EMD and BPM
flow diverter

Drift Tube Temperature Distribution

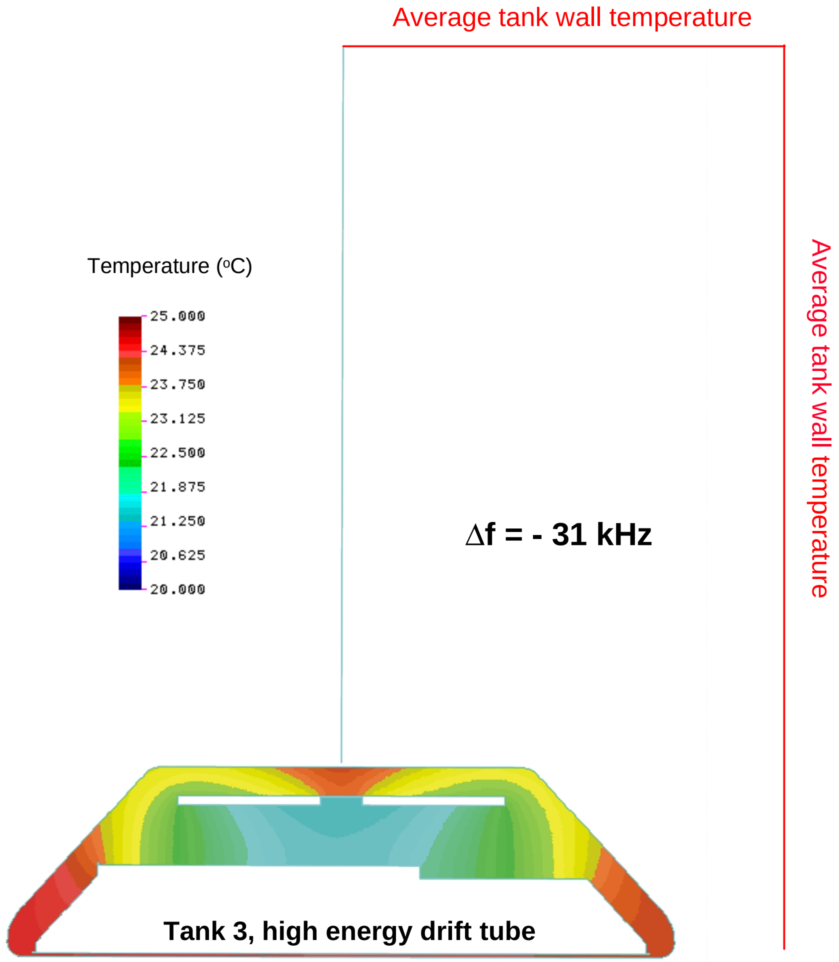


Tank 3, high energy drift tube



- **Flow rate through channels limited to 5.1 gpm (2.5 m/s)**
- **Water temperature in channels = 20°C + ΔT (coolant rise from heat load on stem + 1/2 on drift tube)**

DTL Cell Frequency Shift



- **Both tank (radial & longitudinal) and drift tube deformations contribute to frequency shift**
- **Beam elements added to drift tube model to simulate radial and longitudinal tank growth**
- **Thermal deformations corresponding to temperature profile solved using FEA**
- **FORTRAN code reads displacements and computes cell frequency shift using Slater perturbation theory**

Frequency Shift Studies Results

- **All six tanks must resonate at same frequency (402.5 MHz)**
- **Because of drastic differences in heat load from one tank to another, studies showed that cooling passages can not be designed such that the six tanks have the same frequency shift as a result of RF heating**

➡ **Each tank will be pre-tuned mechanically to given frequency**

  – resonant frequency (no power) will be offset by amount equals to frequency shift
  – will operate at the same resonant frequency during powered operation

Cooling Channel Design

- **Frequency shift must be the same for all cells within same tank to avoid field errors and frequency mismatch**
- **However, heat dissipated on drift tube walls increase as energy level increases**

➡ **To achieve the same frequency shift, amount of cooling is tailored for each drift tube**

  – Larger cooling channel for higher energy level (for tanks 1 and 2)
  – Flow rate adjusted for each drift tube to reach target frequency shift
  – Target frequency shift = frequency shift of high energy drift tube (within each tank)

Tank	1	2	3	4	5	6
Frequency shift (kHz)	-15	-51	-31	-37	-44	-56

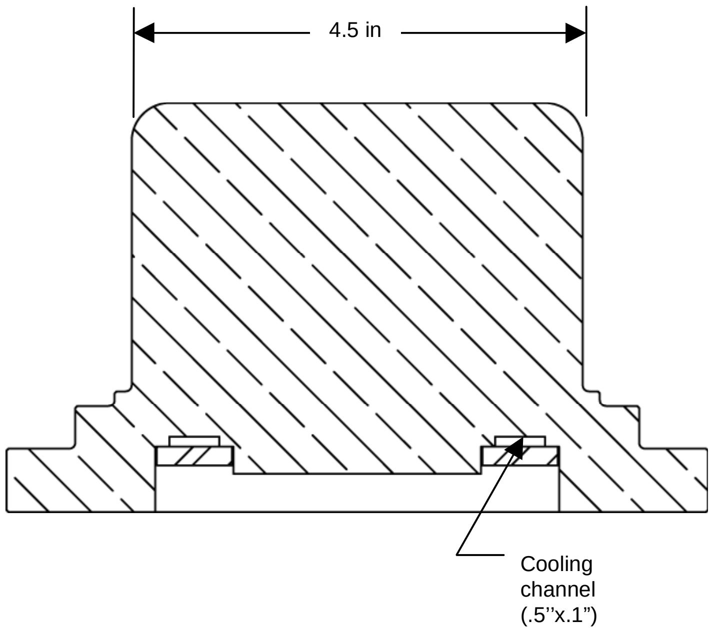
Frequency Shift Studies Results (continued)

- **For a DTL, resonant frequency can be regulated by**
  - Changing the water temperature in the tank walls
  - **And / Or** changing the water temperature in the drift tubes
  - Frequency shift studies help in decision making
- **Frequency *sensitivity* has to be the same for all 6 tanks**
- **Studies showed that this can only be achieved by changing water temperature in both the tank walls and the drift tubes (sensitivity 6-7 kHz/^{o}C)**

DTL Resonance Control Scheme

- **One single cooling circuit per tank (6 cooling carts)**
- **Resonance**
  - Maintained by dynamically adjusting cooling water temperature in both tank walls and drift tubes
  - Uniform frequency shift achieved by balancing flow rate and tailoring cooling channels for each drift tube
  - In practice
    - » Each tank tuned during final assembly to given offset (-15 to -56 kHz) to give a nominal 402.5 MHz resonance during powered operation
    - » Inlet temperature of flow balanced system adjusted during operation to correct for additional frequency shift (sensitivity 6-7 kHz/^{o}C)
    - » Commercial fittings with orifice plates meter flow to drift tubes

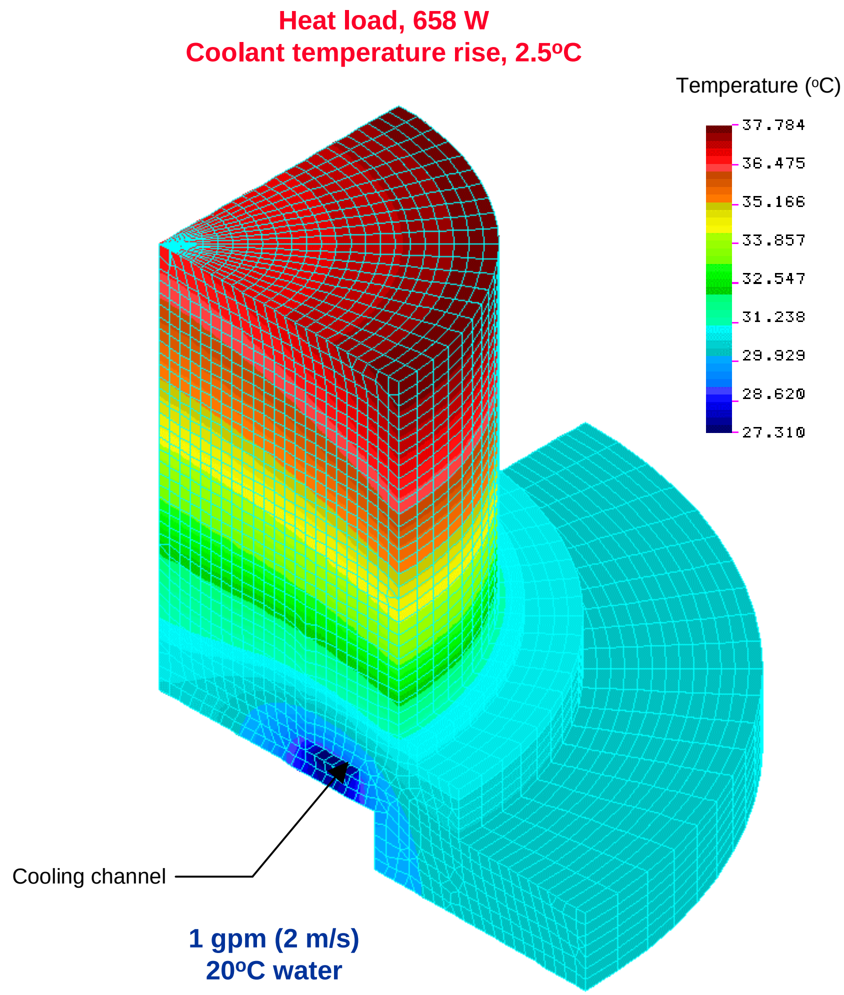
Slug Tuners



- **Used to change the resonant frequency of the DTL by adjusting its penetration into the tank**
- **4 per tank section (68 total)**
- **Maximum penetration 2.25 in**
- **Maximum recess 0.5 in**
- **Penetration determined during low power tuning using dummy adjustable slug tuners**
- **Must be cooled to remove RF waste heat**

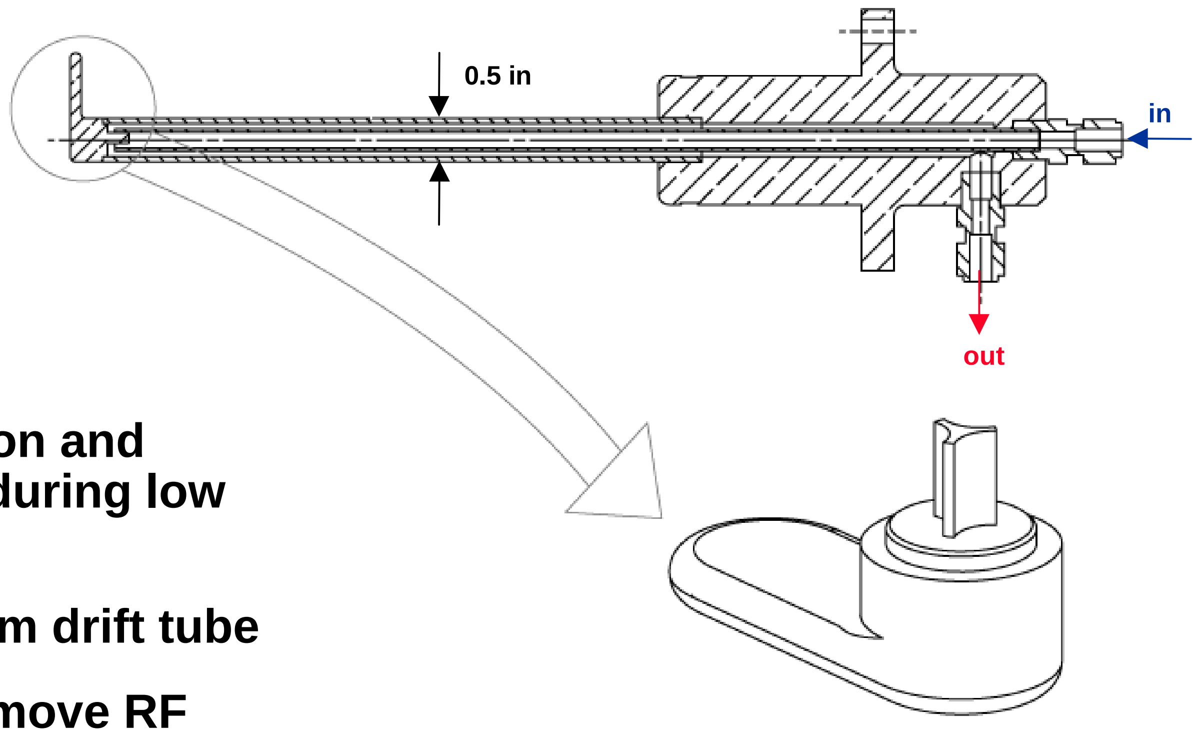
Slug Tuner Cooling

- **Heat load**
  - depends upon penetration in tank (maximum penetration of 2.25 in assumed)
  - same power density as DT stem (at same radial and longitudinal position)
  - assume uniform heat flux of 1.5 W/cm^2 (conservative, corresponds to power density on tip)
- **Flow rate, 1gpm**
- **Heat transfer coefficient applied on edges of cooling channels simulates forced convection boundary condition**
- **Maximum temperature at tip (38°C)**
- **Temperature around RF seal, 31°C**



Post Couplers

- **Used to stabilize the electro magnetic field inside RF cavities**
- **84 to 102 post couplers**
- **Exact number, location and rotation determined during low power tuning**
- **As close as 0.5 in from drift tube**
- **Must be cooled to remove RF waste heat**

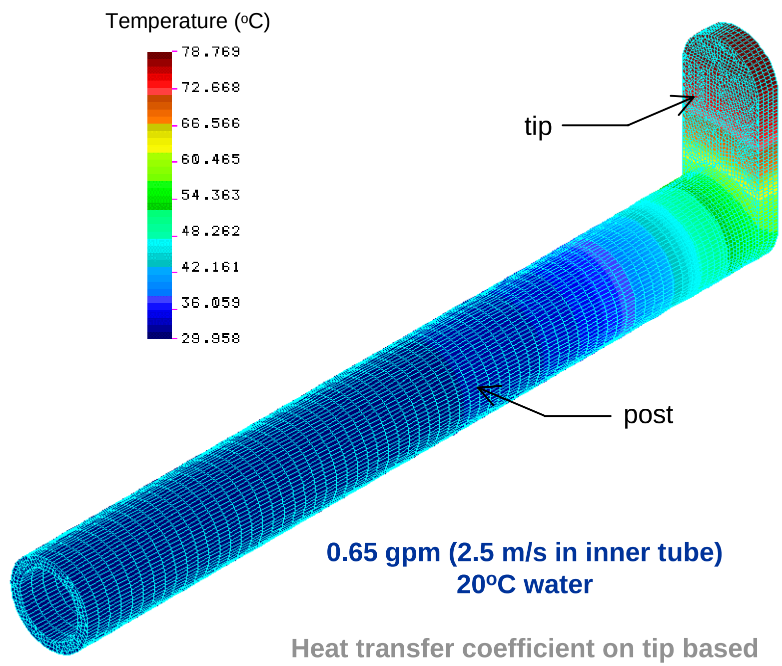


Post Coupler Cooling

- **Heat load**
  - depends upon penetration in tank (worst case assumed, 0.5 in from drift tube)
  - tip: same power density as DT stem (at same radial and longitudinal position)
  - post: 2**average* power density on stem (carries more surface current than stem if excited because of tuning errors)
- **Flow rate, 0.65 gpm**
- **Corresponding heat transfer coefficient to simulate forced convection BC's based on experimental correlation for concentric tubes**
- **Maximum temperature at tip (79ºC)**

4.5 W/cm^2 on tip
4.1 W/cm^2 on post

Total heat load, 282 W
Coolant temperature rise, 1.6ºC



0.65 gpm (2.5 m/s in inner tube)
20ºC water

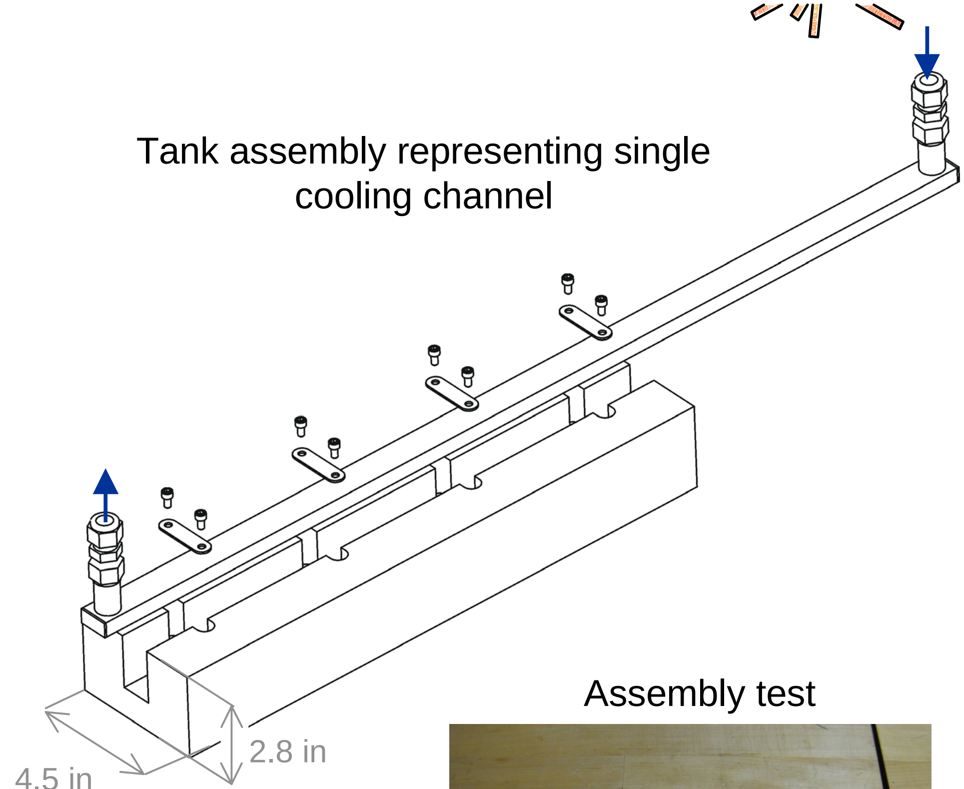
Heat transfer coefficient on tip based upon heat transfer in outer tube (conservative)

Tank Cooling Scheme Testing

- **Tank prototype used to:**
  - test procedure to assemble cooling channels
  - verify effectiveness of the thermal grease as a heat transfer path
  - benchmark tank FE model used to predict tank temperature profile

- **3 types of non-silicone based thermal grease were tested**
  - Manufactured by AOS Thermal Compounds
  - oil thickened with metal fillers
  - $0.7 < k < 2.5$ W/mK
  - unaffected by radiation level around DTL (1.8×10^6 Rads for a 25 year period)

Tank assembly representing single cooling channel



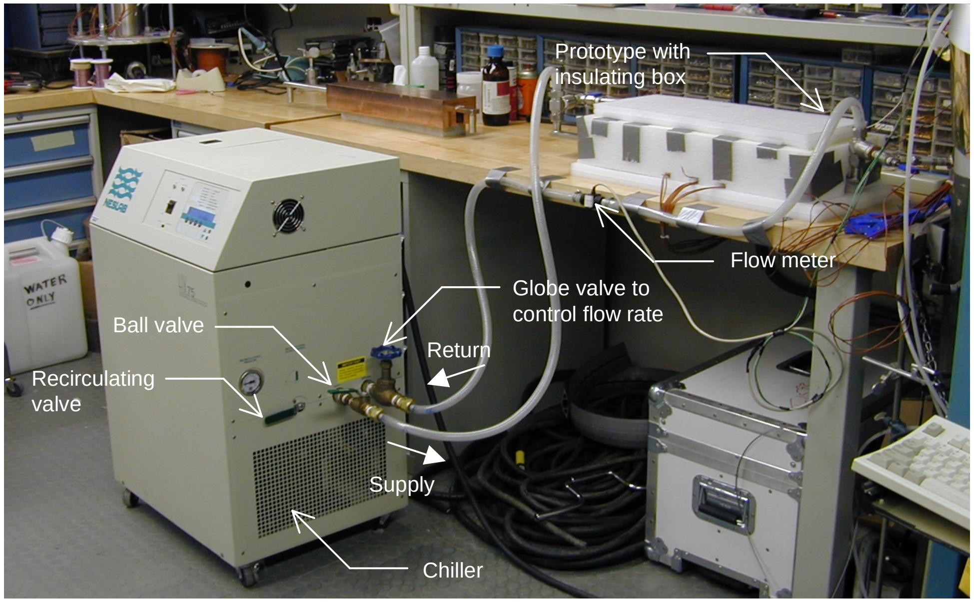
Assembly test

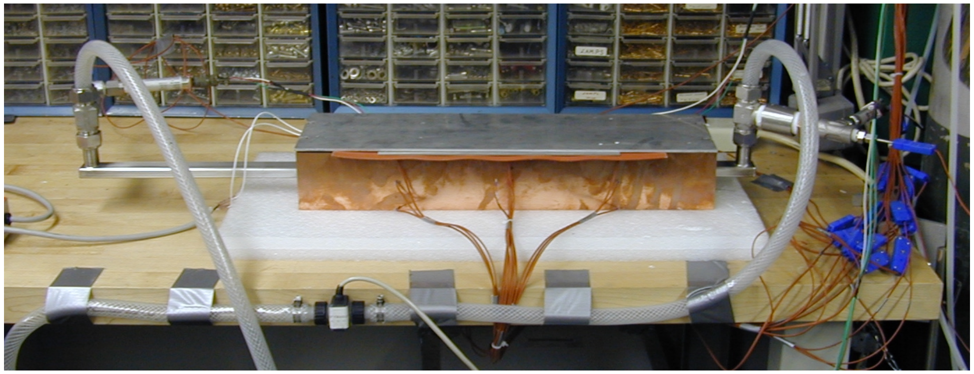
Heat Transfer Test

- **Transient test**
- **Start at room temperature and circulate cold water in channel**
- **Overall system thermal resistance evaluated by measuring cool-down of steel section vs time**

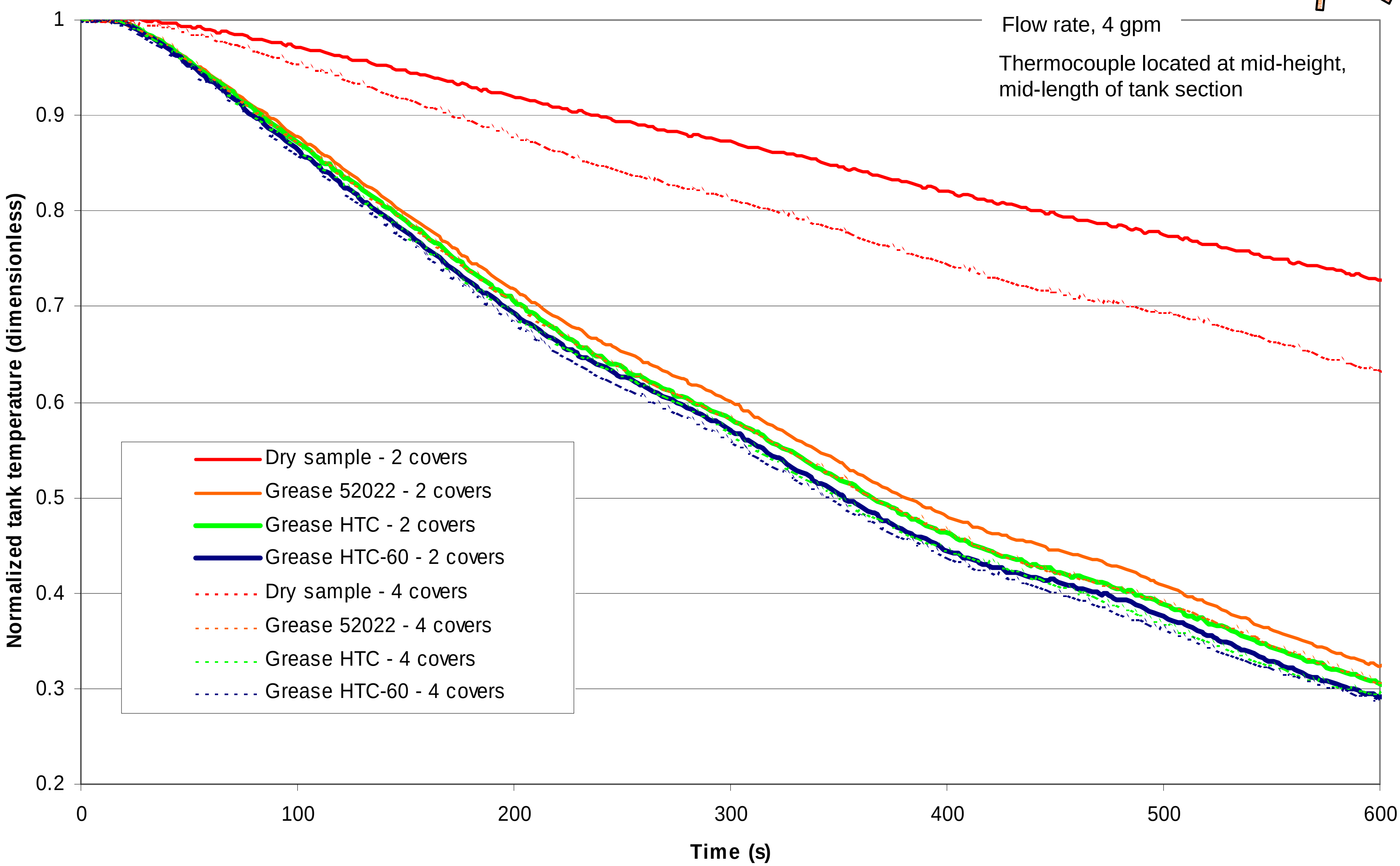
slope = direct measure of resistance

$$\frac{d}{dt}\left[\frac{T_{steel}-T_{water}}{T_{init}-T_{water}}\right]_{t\approx 0}=-\frac{1}{R_{eq}}\cdot\frac{1}{\rho\cdot C_p\cdot V_{steel}}$$



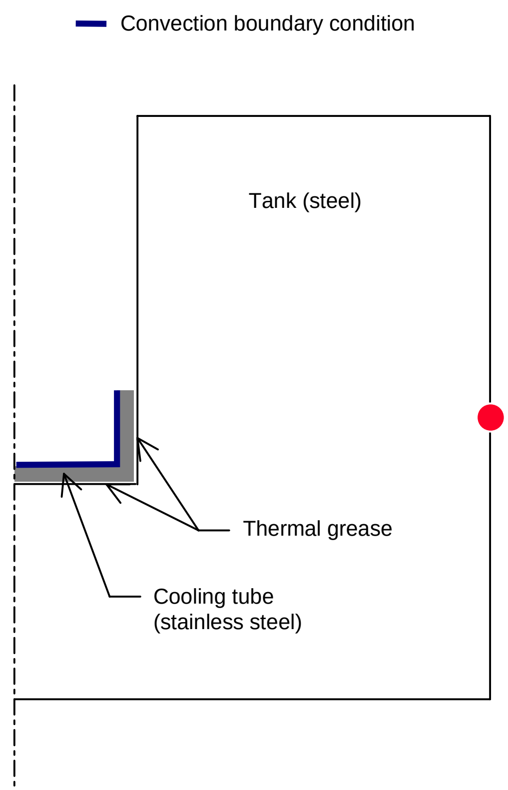


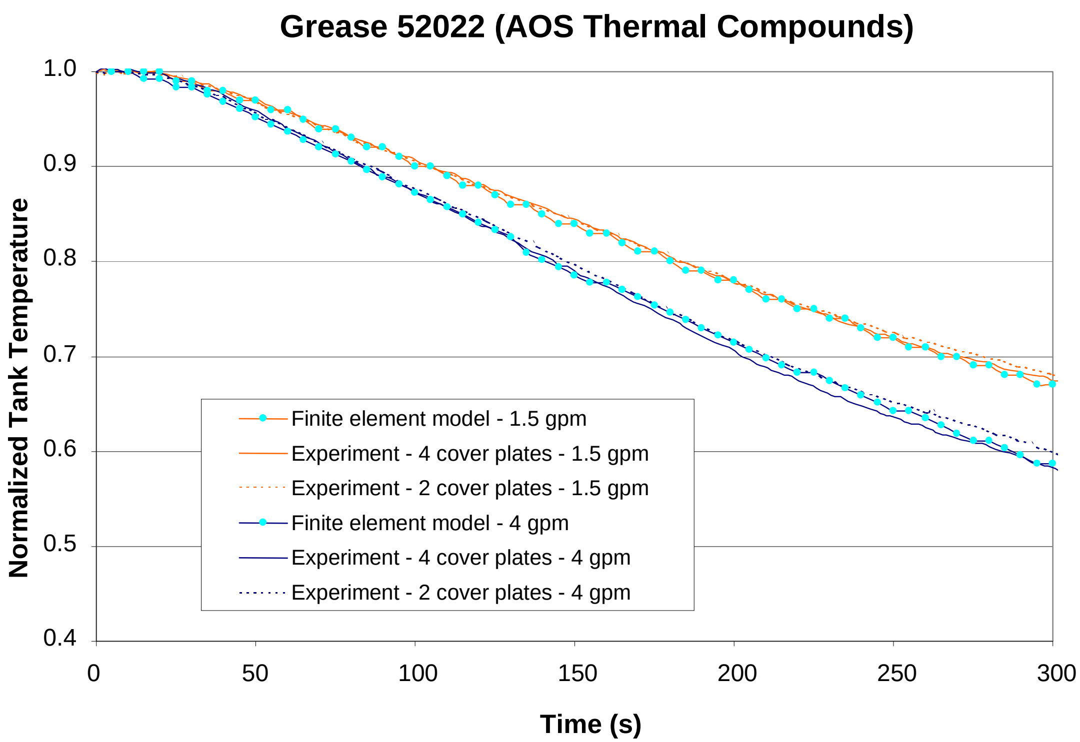
Thermal Grease Effectiveness



Tank Finite Element Model Benchmark

Tank model to simulate experiment





k_{grease} = 0.7 W/mK (per manufacturer)
.002" grease layer on bottom groove (measured)
vertical gaps filled with grease (.02")

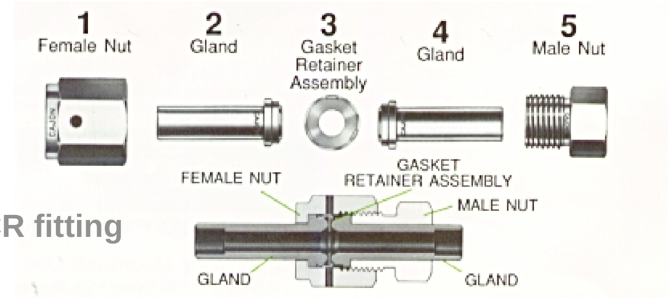
Tank Cooling Scheme Testing Summary

- **Thermal grease easy to use both in assembly and disassembly of cooling channel**
- **Improvement by a factor of 3 of heat transfer performance (compared to a dry-mounted cooling channel)**
- **No evidence of improved heat transfer performance observed with high-end (most conductive) thermal grease compounds**
  - higher viscosity make more conductive compounds harder to spread evenly and more prone to trap air bubbles?
  - ➡ Grease 52022 (AOS) selected based upon ease of installation and cost
- **FE model used to simulate experiment predicts heat transfer performance extremely well**
  - ➡ model of the DTL tank using the same assumptions should simulate accurately the temperature distribution caused by RF heating

(see LA-UR-00-3623 for more details)

VCR fitting is used to meter the flow

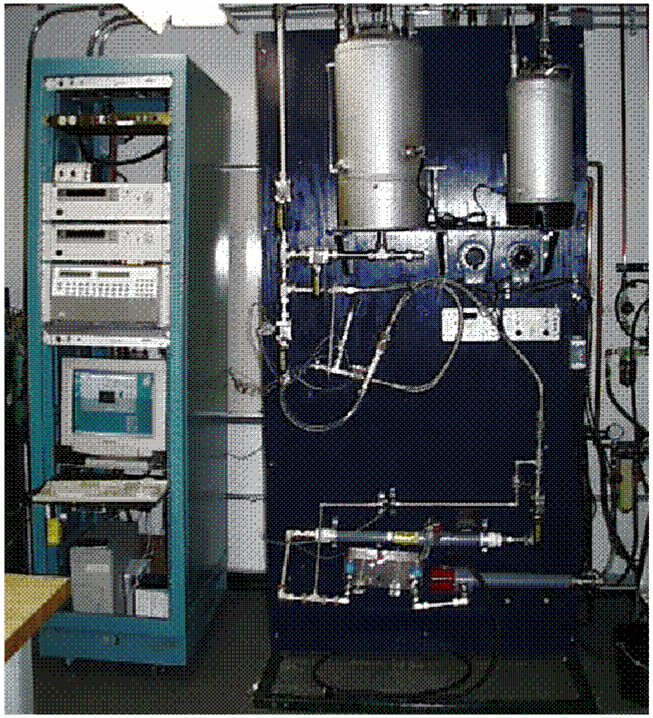
- **To maintain resonant frequency, each drift tube requires unique flow rate**
- **Standard flow meters or orifices too costly. Off-the-shelf fittings + gaskets can be used instead**

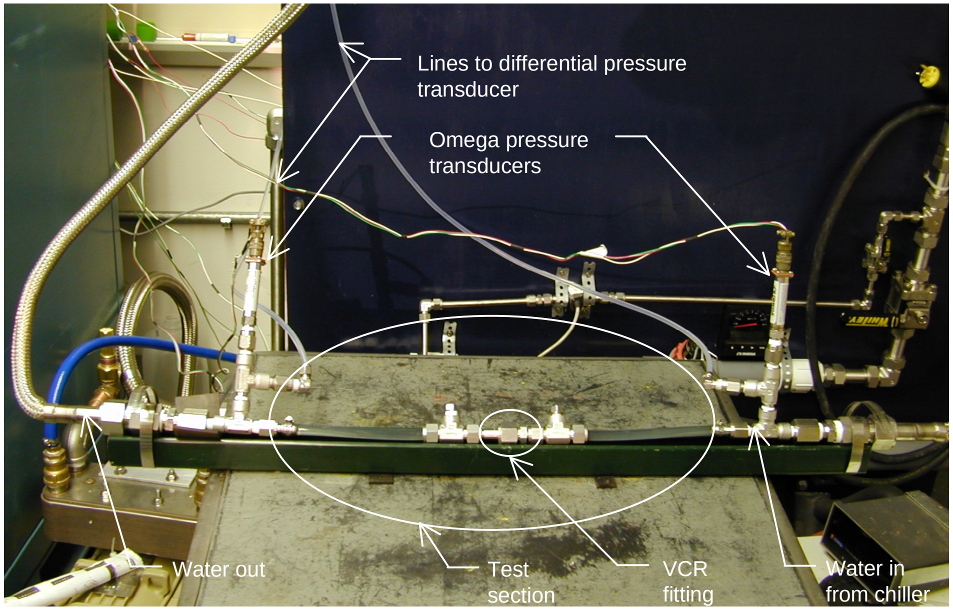


Cajon VCR fitting

- **Characterize VCR fitting experimentally to validate empirical correlations**

VCR Fitting Testing



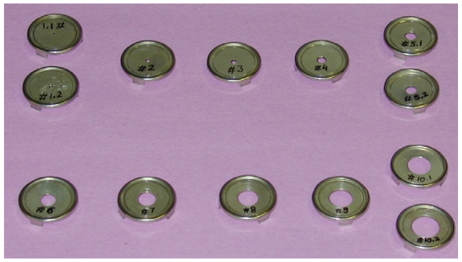


– Pressure drop across VCR fitting function of the square of the water flow rate times a constant (flow resistance)

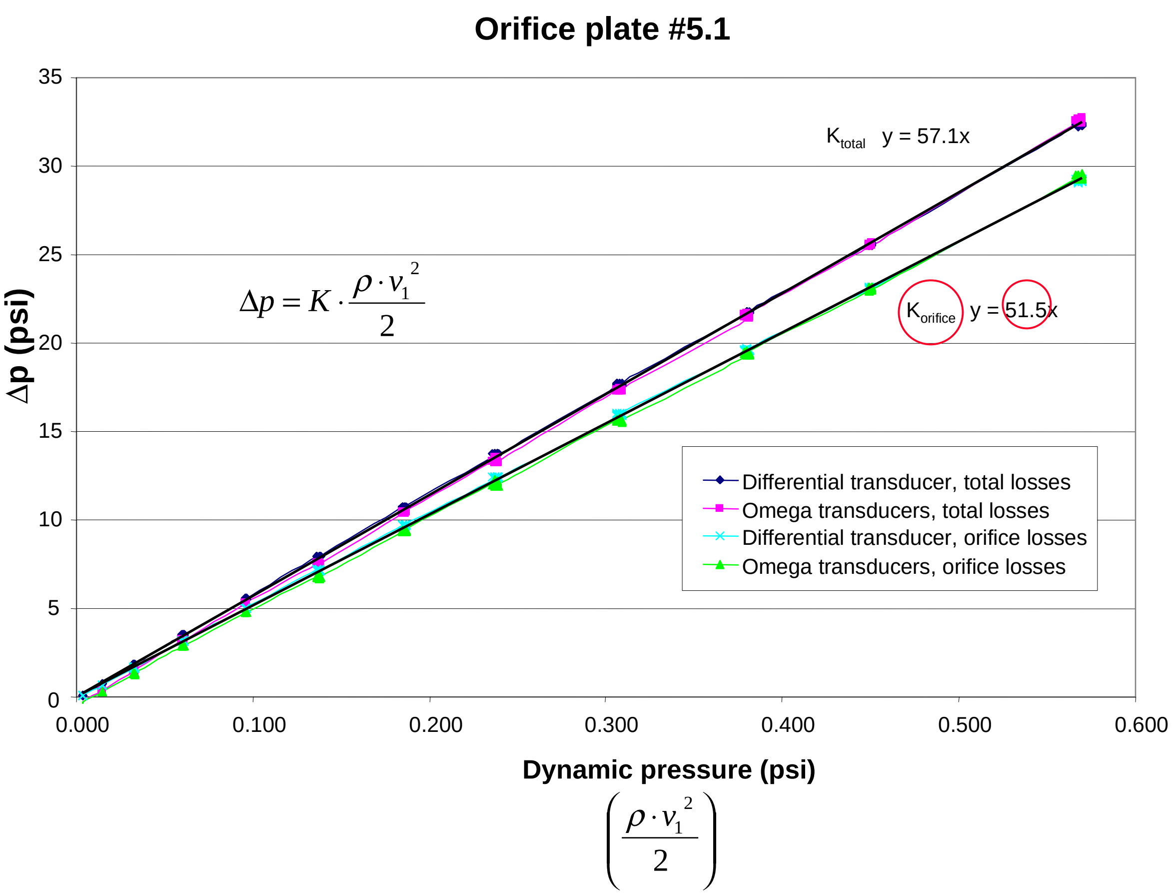
⇒ flow resistance is evaluated by measuring pressure drop

– Both 1/2" and 3/4" VCR fittings tested using ESA-DE flow loop

Gaskets for the 1/2" fitting



VCR Fitting Testing Results

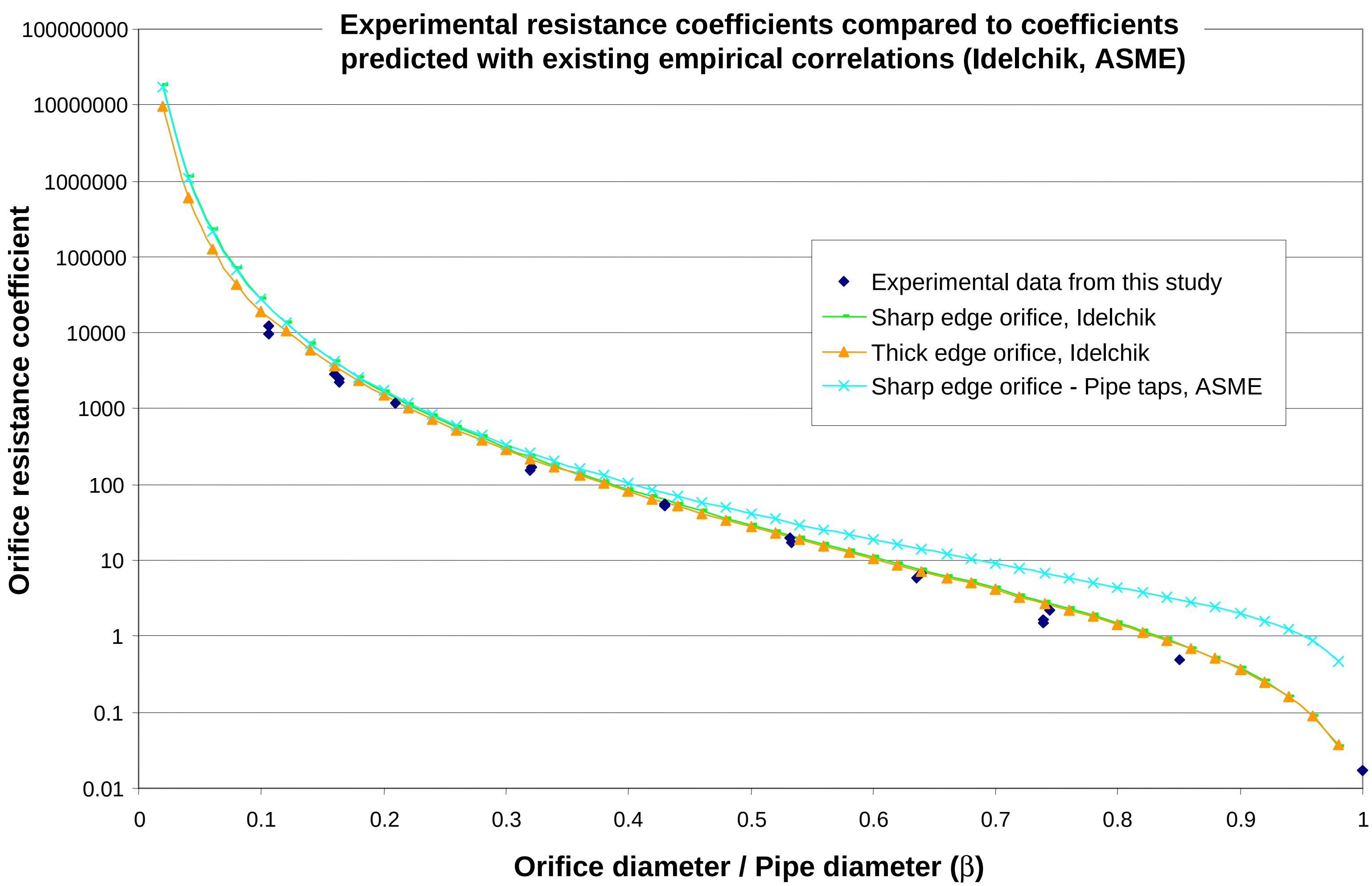


- Pressure drop across orifice function of :
  - » orifice flow resistance coefficient, *K*
  - » velocity upstream, v_1

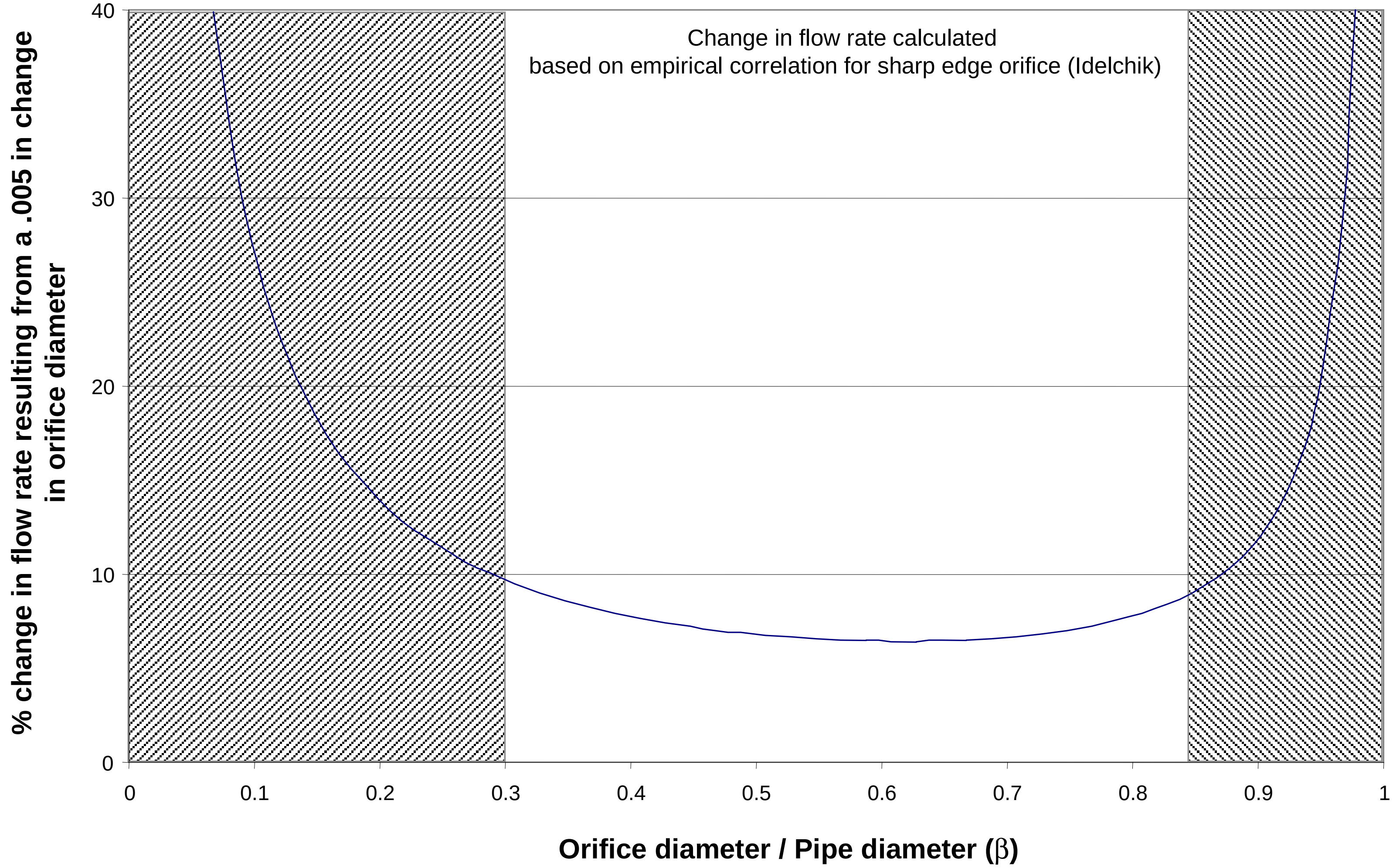
$$\Delta p = K \cdot \frac{\rho \cdot v_1^2}{2}$$

- For a given orifice, K
  - » is constant and does not depend upon flow rate
  - » can be evaluated using least square fit of pressure drop across orifice
- Pressure drop across VCR fitting without orifice plate not negligible (needs to be subtracted from total pressure drop measured)

VCR Fitting Testing Results



Flow Rate Sensitivity with respect to Changes in Orifice Diameter



VCR Fitting Testing Summary

- **Drilled off-the-shelf fittings makes efficient flowmeters**

- **Flow resistance measured for wide range of orifice plates**

- **Experimental results agree well with sharp edge correlation**
  - ➡ **sharp edge orifice correlation used for design**

- **Sensitivity to orifice diameter increases for small/large orifices**
  - ➡ **use orifice plates with β in the 0.3 to 0.85 range**

(see LA-UR-00-2487 for more details)

What's Next? (Analysis)

- **Finalize flow rate requirements & frequency shift studies**
  – Adjust heat flux as a function of temperature (non linear effects, small ~ 5%)
  – Modify tank FE model to reflect testing results

- **Evaluate frequency shift from slug tuner and post coupler thermal expansion**

  (expected to be small and not a problem)

- **Evaluate drift tube movement caused by RF heating**

What's Next ? (Testing)

Drift tube prototype
Tank 1

- **Flow rate through drift tube function of resistance coefficients of orifice plate and drift tube**

  ⇒ evaluate pressure drop across drift tubes

- **Drift tube flow tests**
  - 6 drift tube prototypes
  - Measure flow resistance using ESA-DE flow loop
  - Generalize test results and develop analytical correlations to calculate pressure drop in each drift tube

- **Before final installation, pressure drop across each drift tube + orifice plate checked at nominal flow rate**

SNS Drift Tube Linear Accelerator
Preliminary Design Review
September 26 & 27, 2000

Thermal/Structural Analysis of the Endwalls and Iris

Snezana Konecni

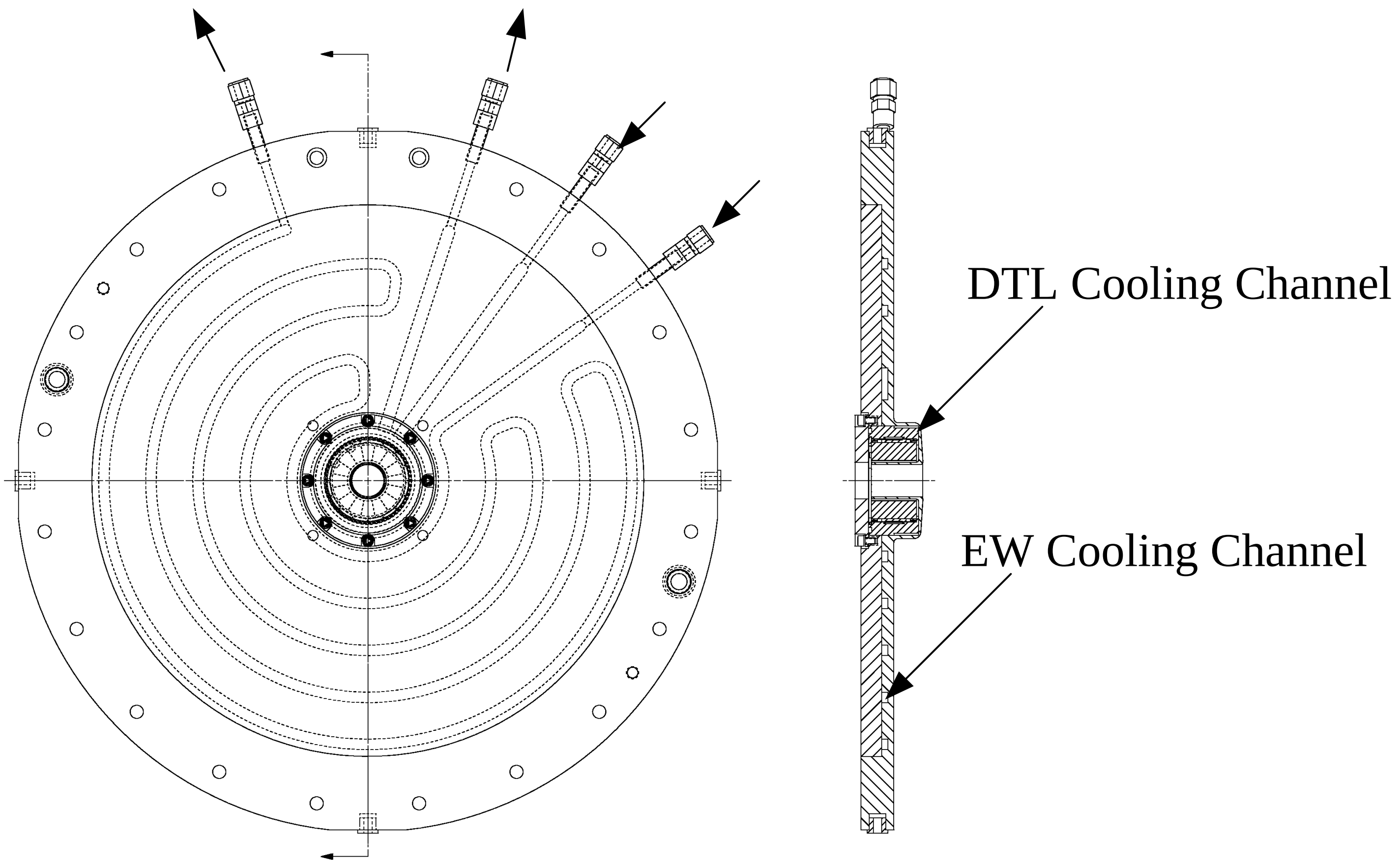
Outline

- Geometry
- Characteristics
- Analysis
- Results and Summary

Characteristics

- **Six DTL Tanks**
- **Twelve endwalls with half drift tube attached**
- **Power**
  - Tank1: 130 W (15 W DT and 115 W Endwall)
  - Tank6: 3164 W (754 W DT and 2410 W Endwall)
- **Material:**
  - Copper plate 1” thick for the endwall and DT
  - Steel tank
- **Assumptions:**
  - Temperature of the tank constant
  - Brazed Copper cover plate

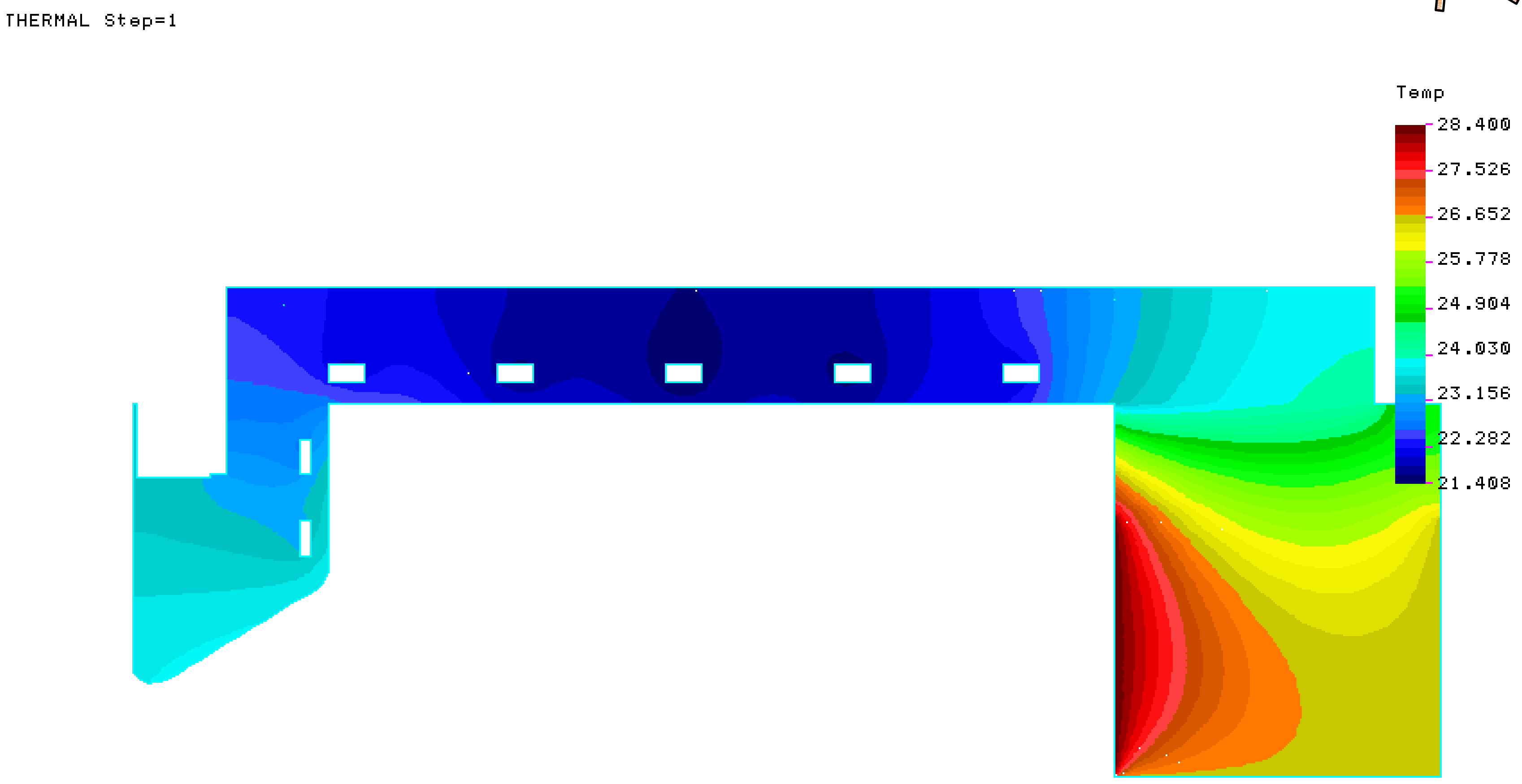
Geometry - Endwall Tank 1



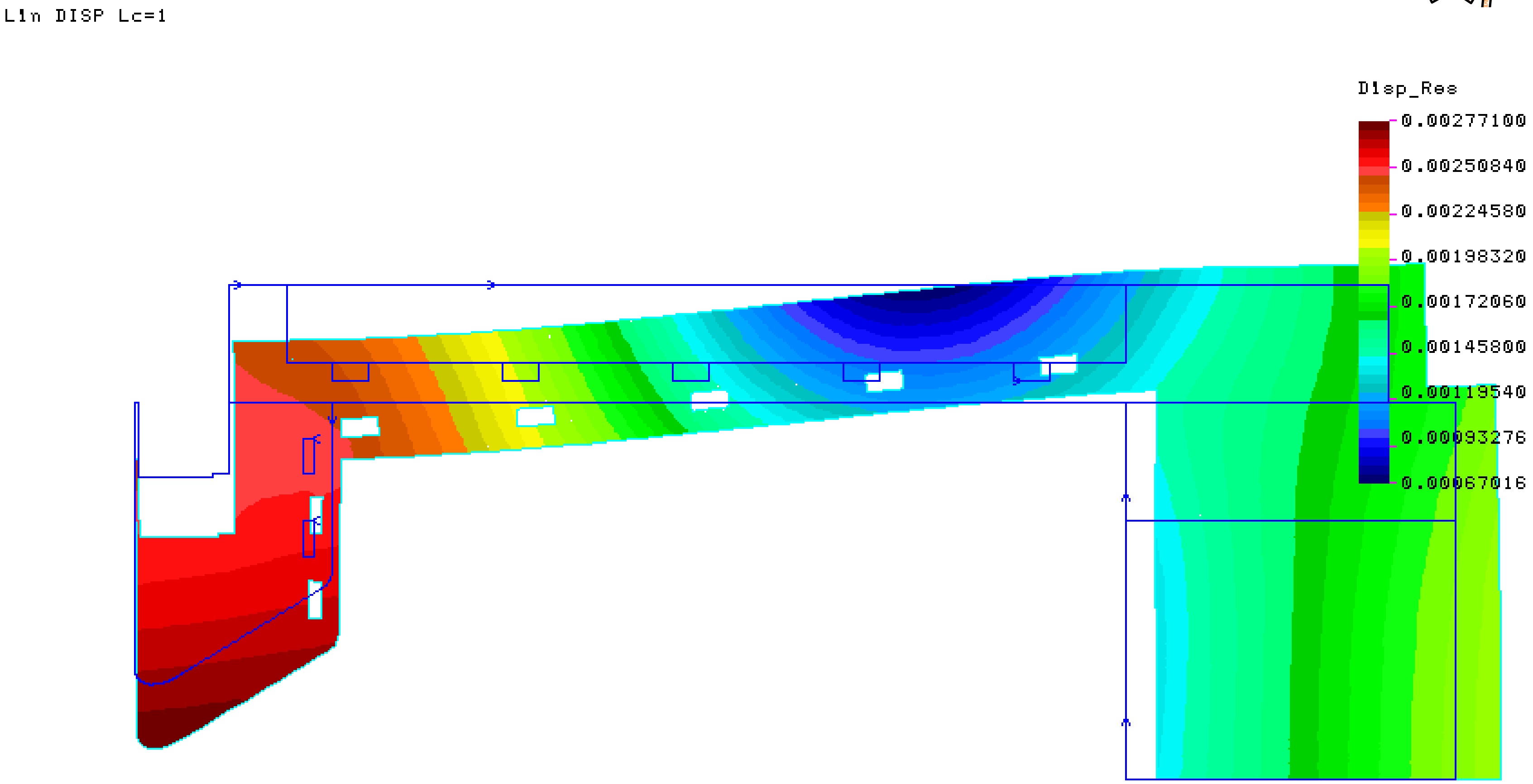
Analysis

- **2-D axisymmetric model in COSMSO/M**
- **Power input as a Heat Flux determined in SUPERFISH**
- **Variable Heat Flux**
- **Needed water flow determined through matching Frequency Shift with the Frequency Shift from the Drift Tube Analysis.**
- **Water cooling represented through Heat Transfer Coefficient**
- **Cooling water flowrates:**
  - 1 gpm in the endwall channels
  - 0.05 to 1.8 gpm in the drift tube channels

Temperature of Endwall Tank 3-Low Energy End

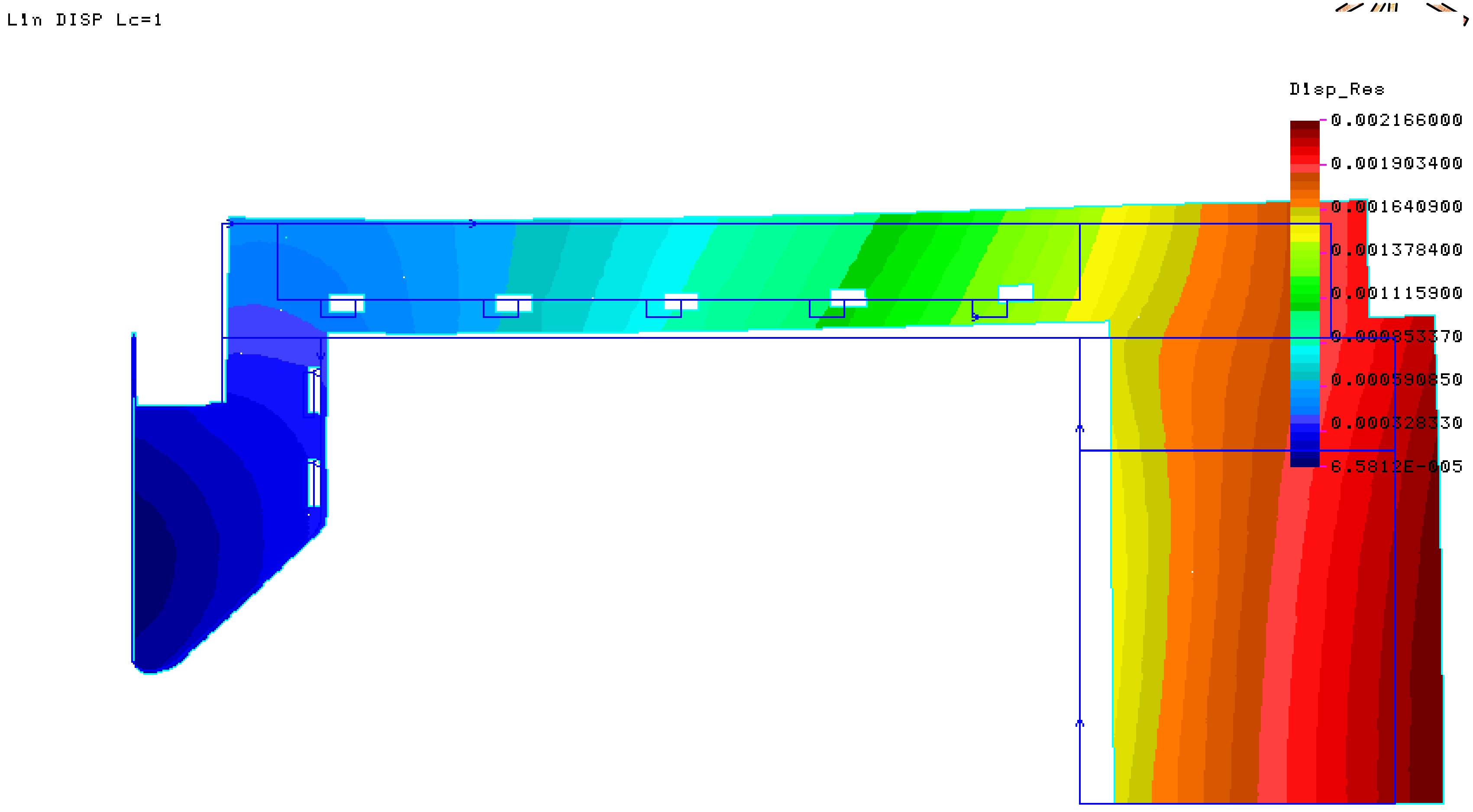


Displacement for Tank 3 Low Energy End



Frequency Shift = -116 kHz

Displacements (cm) Tank 3- High Energy End



Maximum Stresses are below the maximum yield strength of Copper

Results and Summary

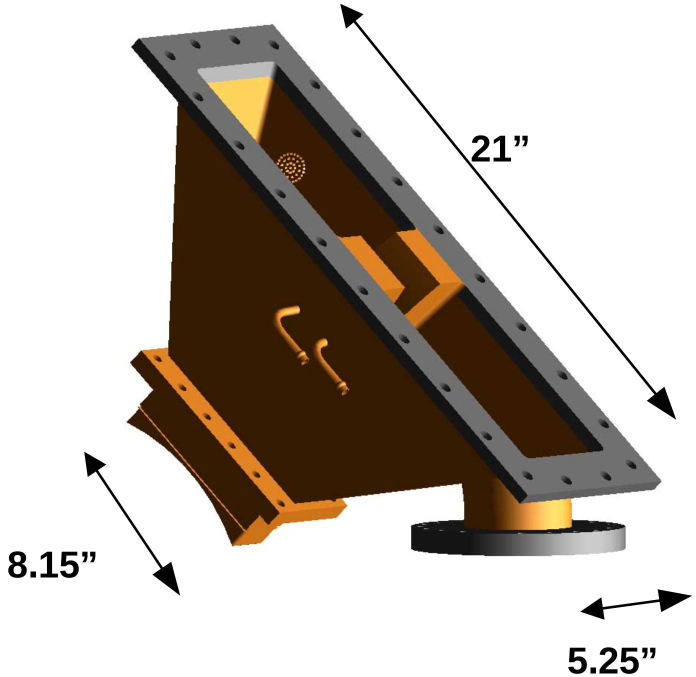
tank	end cooling channels flow (gpm)	drift tube cooling channels flow	frequency shift (heat) kHz	frequency shift pressure kHz	FS +1 C	velocity ewch	velocity dtch	Reew	Redt	dt channel width (cm)	dt channel dept	#of dt channels	ew channel width	ew ch hight	Tave	Trad	DT dp (psi)	EW dp (psi)	power for ew and dt	power at the nose
1-front	0.2	0.05	-15.2	-450	-13.26	0.43	0.43	2297	1148	0.381	0.191	1	0.762	0.381	20.8	21	0.68	0.642	129.85	15.55526
1-end	1	1.4	-14.8	-247	-14.9	2.17	2.28	11488	9047	0.762	0.254	2	0.762	0.381	25.7	26.9	8.28	11.33	1055.313	165.1989
2-front	0.5	0.25	-52	-278	-52.11	1.05	0.815	5744	3231	0.762	0.254	1	0.762	0.381	24.3	25.5	1.36	3.28	1082.684	170.1979
2-end	1	0.9	-50.3	-157	-52.96	2.1736	1.46	11488	5816	0.762	0.254	2	0.762	0.381	26.2	27.9	3.77	11.33	1881.482	3.90E+02
3-front	1	0.7	-31.4	-116	-33.558	2.1736	1.14	11488	4524	0.762	0.254	2	0.762	0.381	26.6	28.4	2.4	11.33	1984.35	341.1793
3-end	1	1.4	-31.4	-91	-34.24	2.1736	1.71	11488	7238	1.016	0.254	2	0.762	0.381	26.6	28.4	4.65	11.33	2289.7	449.5657
4-front	1	0.9	-37.3	-96	-40.11	2.17	1.1	11488	4652	1.016	0.254	2	0.762	0.381	26.6	28.4	2.19	11.33	2300.07	453.1532
4-end	1	1.5	-37.5	-85	-40.61	2.17	1.83	11488	7755	1.016	0.254	2	0.762	0.381	26.6	28.4	5.26	11.33	2540.23	543.2255
5-front	1	0.9	-44.4	-92	-47.56	2.17	1.1	11488	4652	1.016	0.254	2	0.762	0.381	26.6	28.4	2.19	11.33	2548.89	546.558
5-end	1	1.5	-44.5	-86	-47.71	2.17	1.83	11488	7755	1.016	0.254	2	0.762	0.381	26.6	28.4	5.26	11.33	2737.3	622.3488
6-front	1	0.7	-56	-97	-59.18	2.17	0.85	11488	3618	1.016	0.254	2	0.762	0.381	26.6	28.4	1.35	11.33	2746.43	625.6023
6-end	1	1.8	-56.5	-94	-59.79	2.17	2.2	11488	9305	1.016	0.254	2	0.762	0.381	27.2	29.2	7.3	11.33	3164.4	754.5626

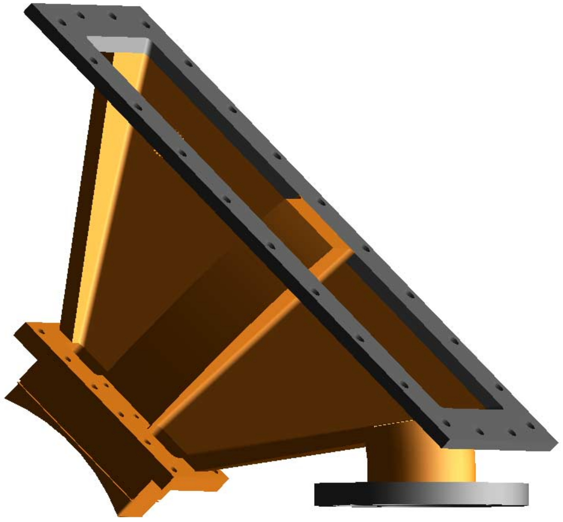
- Frequency shift sensitivity range: 18 - 2.8 kHz/°C

Outline of the Iris Analysis

- Iris
- Characteristics and Loads
- Thermal/Structural analysis of the Iris
- Summary

Thermal and Structural Analysis of the Iris

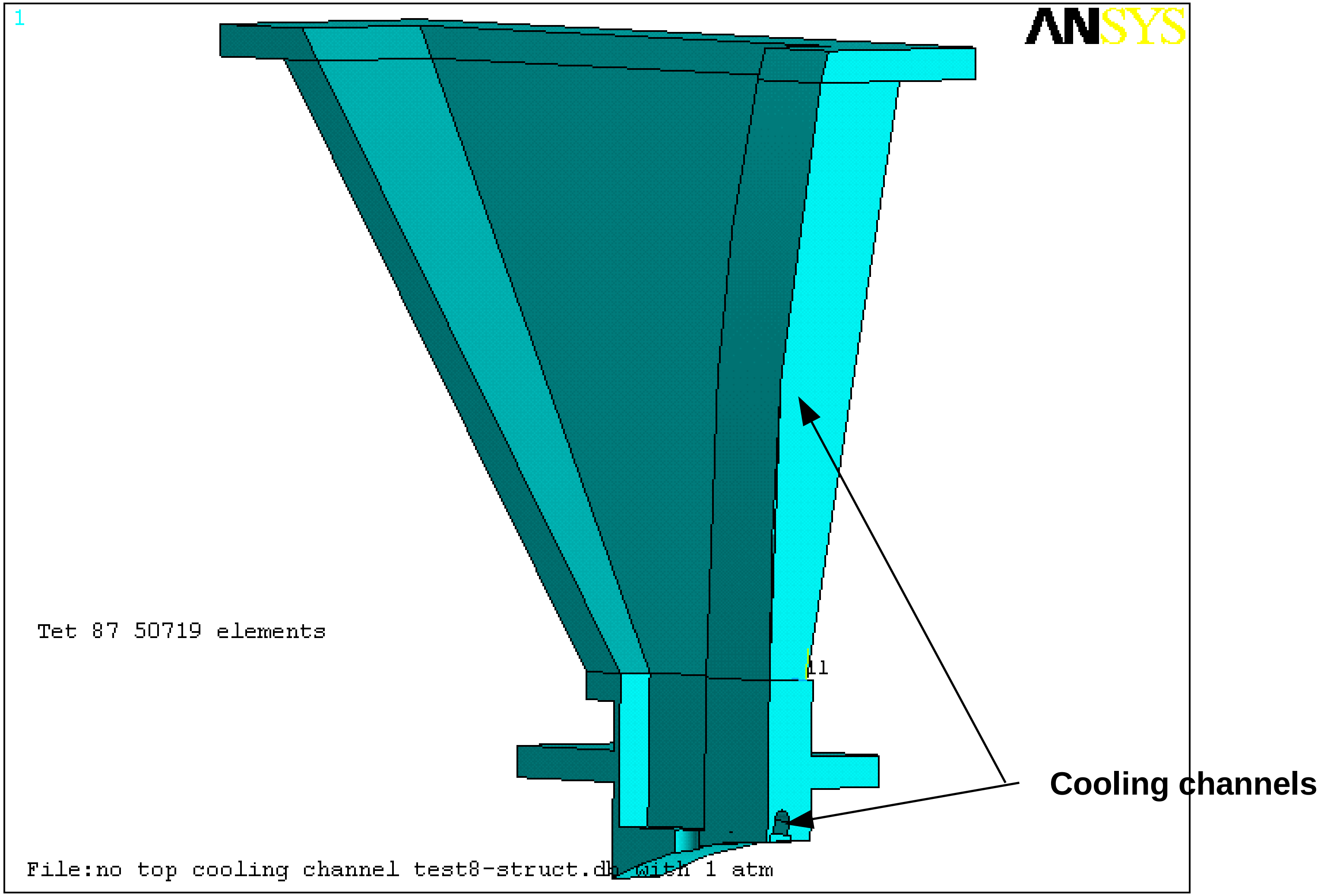




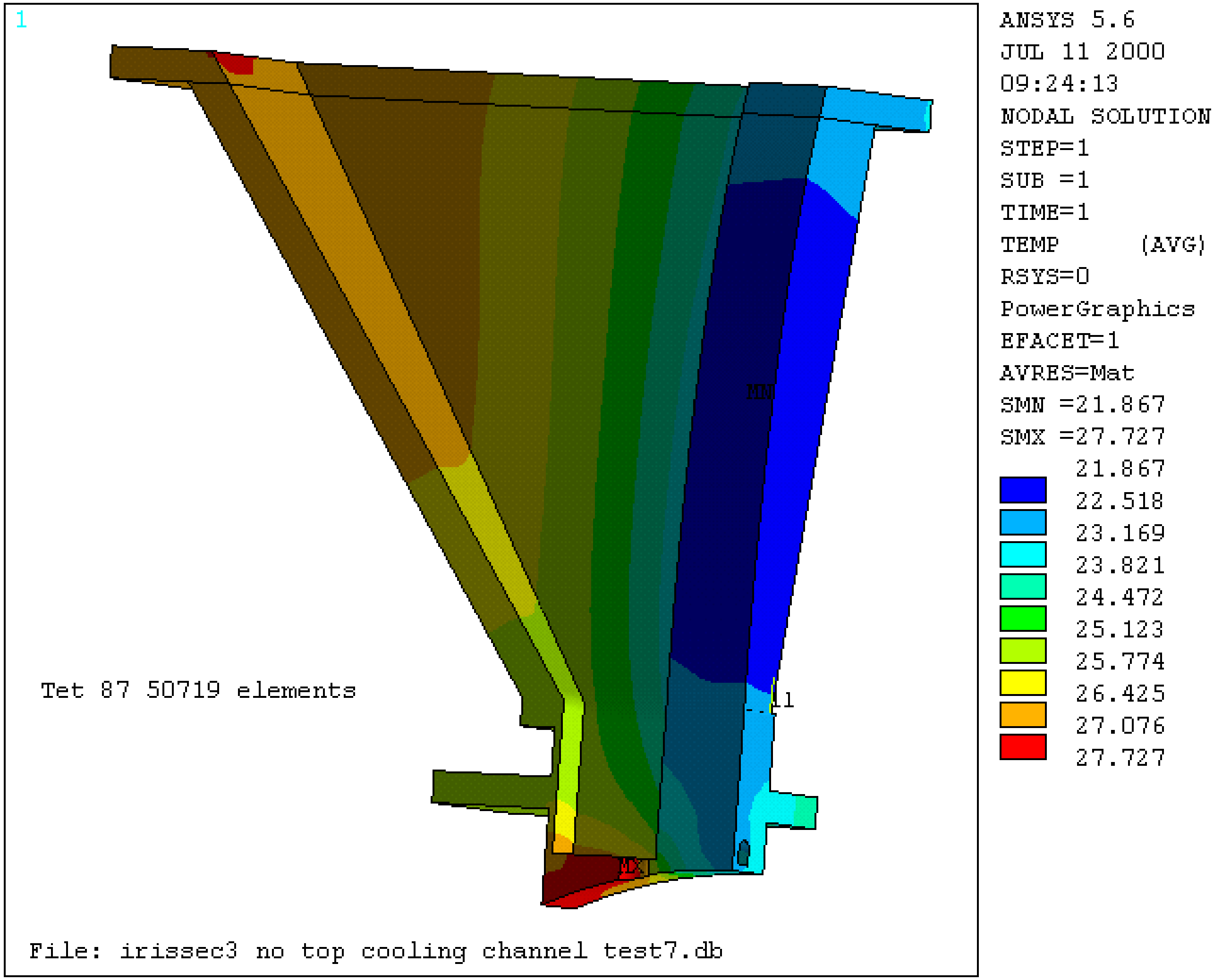
Characteristics

- 10.5 W/cm at the stainless steel flange (CW load).
- 40 W/cm at the perimeter of the bottom of the iris (CW load).
- 1.5 W/cm^2 at the iris cutouts (CW load).
- 6.5 W/cm^2 load from the DTL tank 6 (CW load) on the surface exposed to the tank.
- 65 W/cm^2 power density on the 0.5" tuning slot cutouts of the iris (CW load).
- Duty factor is 7%.
- Safety factor is 2.
- Cooling channels (d=5/16") inside the wedge and at the bottom of the iris by the slot.
- Flow rate is 1.57 gpm. Velocity of the water inside the channel is 1.0 m/s in the feed (heat transfer coefficient is 4550 W/m^2), and 1.13 m/s (heat transfer coefficient is 5395 W/m^2) in the channel. Inlet water temperature is 20°C.
- Pressure drop in the cooling channel is 0.184 psi (1.57 gpm). For two sides it is 0.368 psi.
- Heat transfer coefficient in the cooling channel (8 by 4 mm) near the RF window flange is 5000 W/m^2 at 20°C. The flow rate is 0.523 gpm. There are two channels. Total flow is 1.46 gpm
- Pressure drop at the top per cooling channel is 0.64 psi. Both channels 1.28 psi.

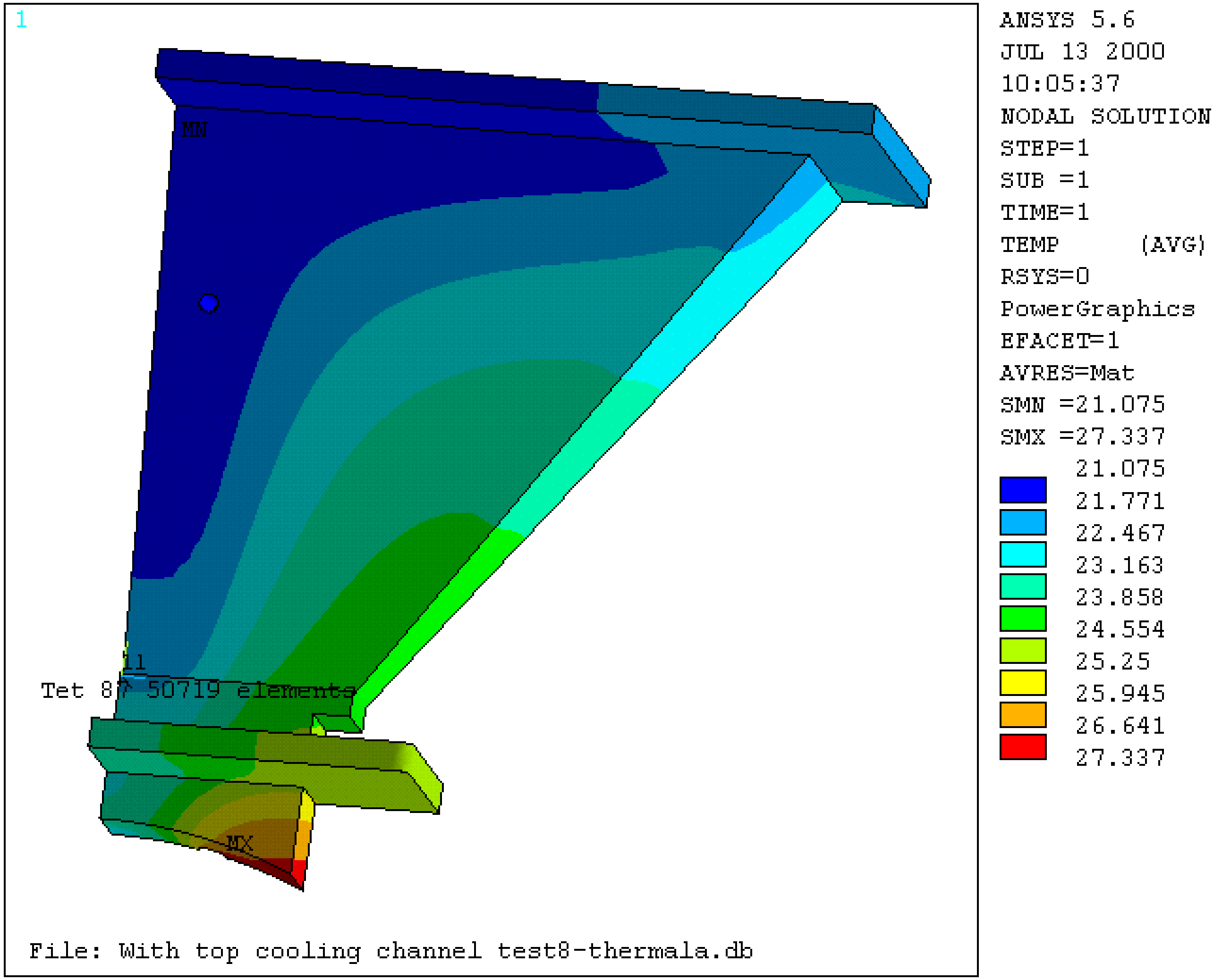
Analysis model



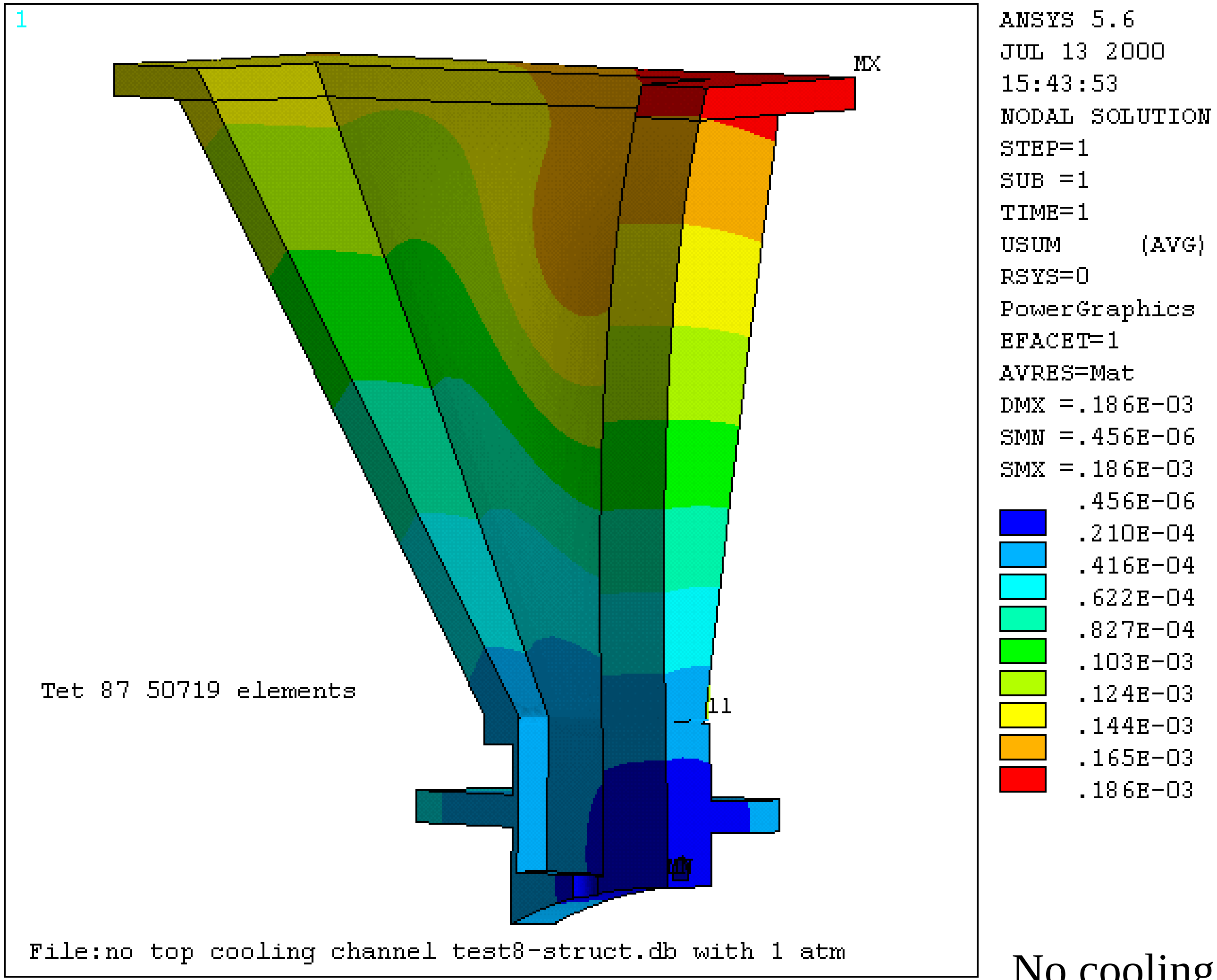
Temperature no top channel



Temperature with top channel

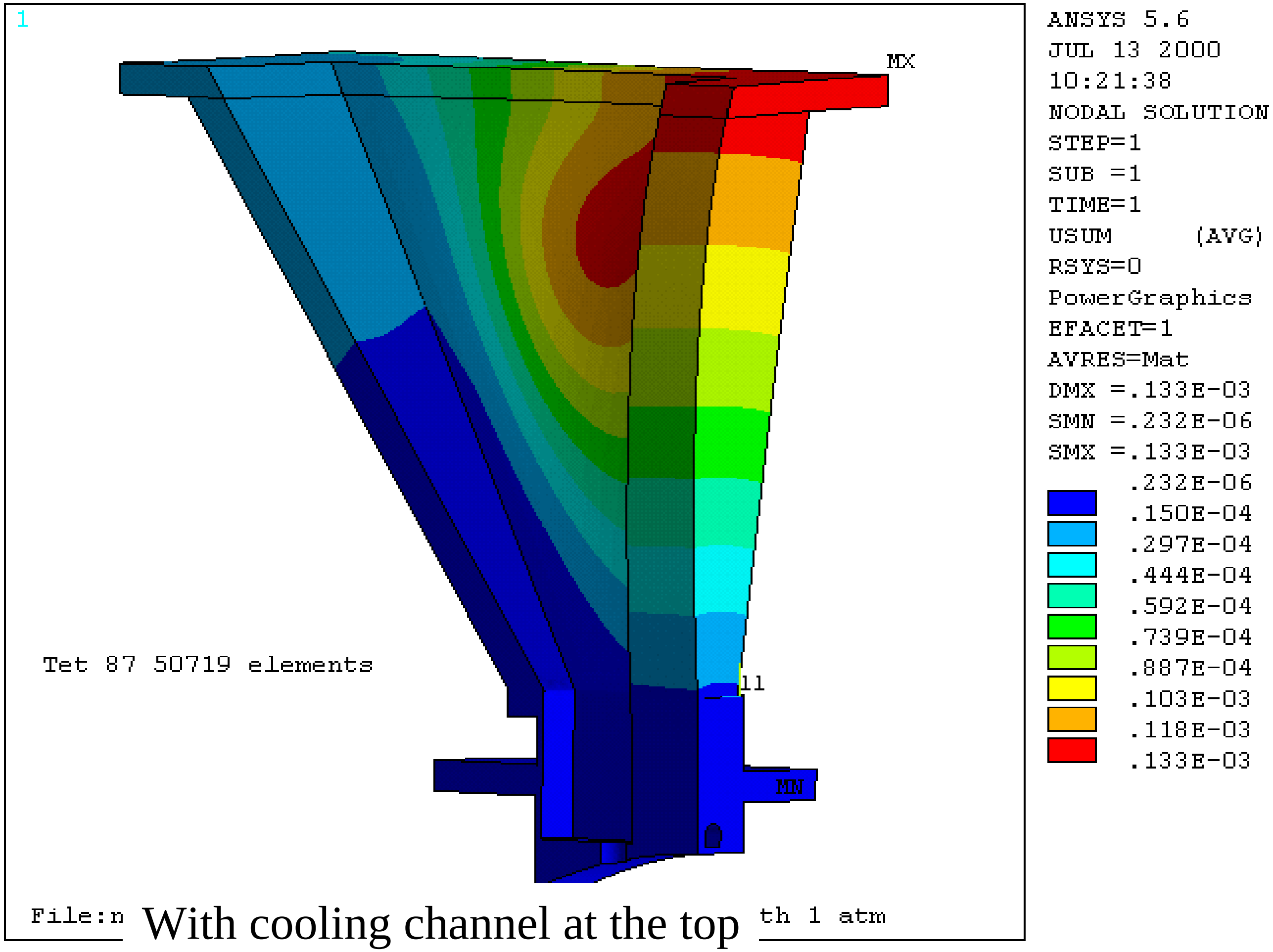


Displacements (m)



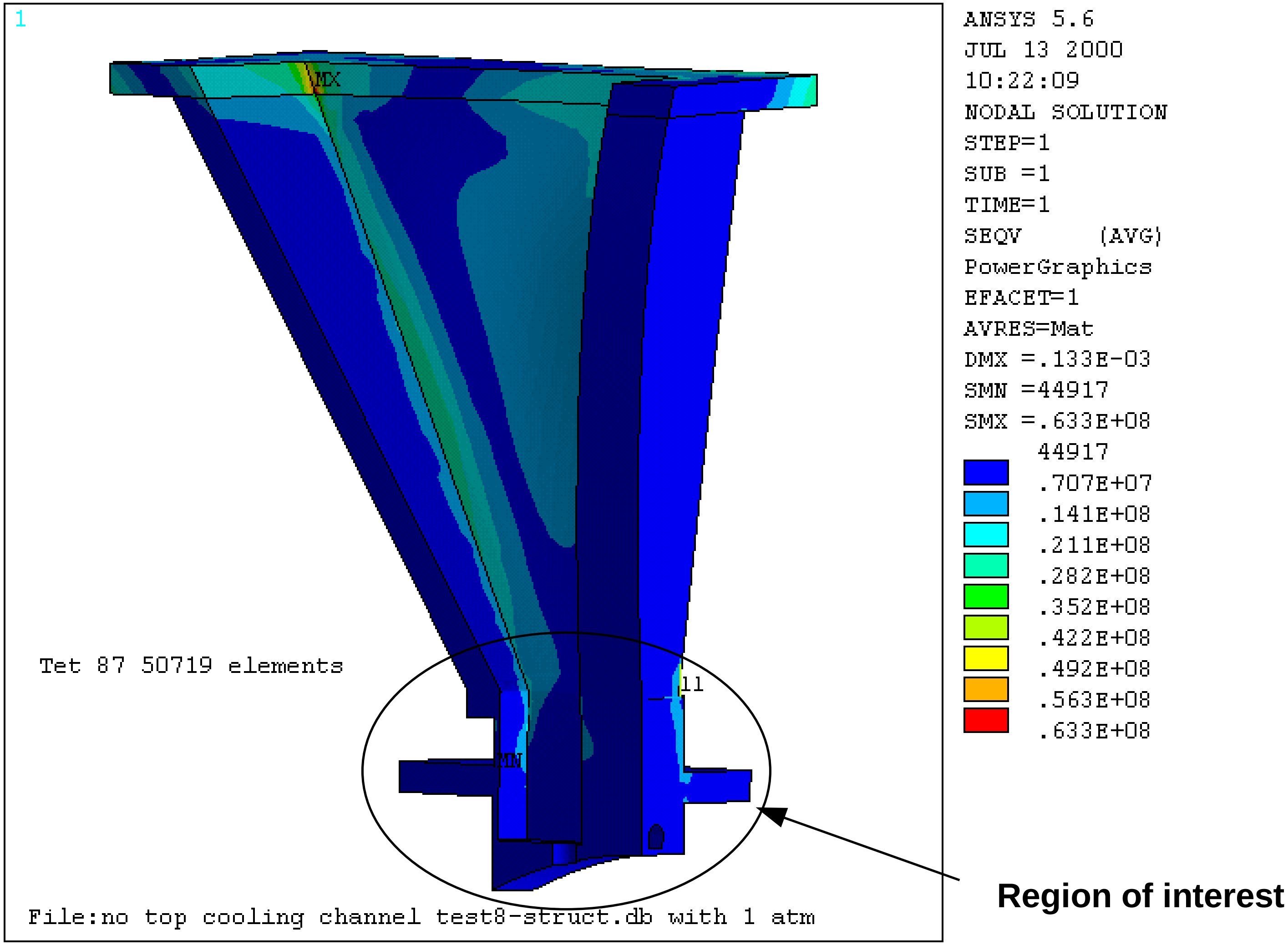
No cooling channel at the top

Displacements (m)



With cooling channel at the top

Stress contours



Copper yield point 58 MPa

Summary

- For the current loading it can be seen from the results that 3.14 gpm is an adequate flow of water for cooling the iris.
- The maximum displacement is 0.123e-04 m.
- Displacements in the slot region are in the order of $1*10^{-5}$ m and that will not cause large frequency shifts.
- Adding cooling channel near the RF window flange with a 1gpm water flow for a half-iris, changes the temperatures at the flange.
- Pressure from the outside has the largest contribution to the stresses and displacements.

SNS Drift Tube Linear Accelerator
Preliminary Design Review
September 26 & 27, 2000

DTL Dynamics Analysis

Steve Ellis

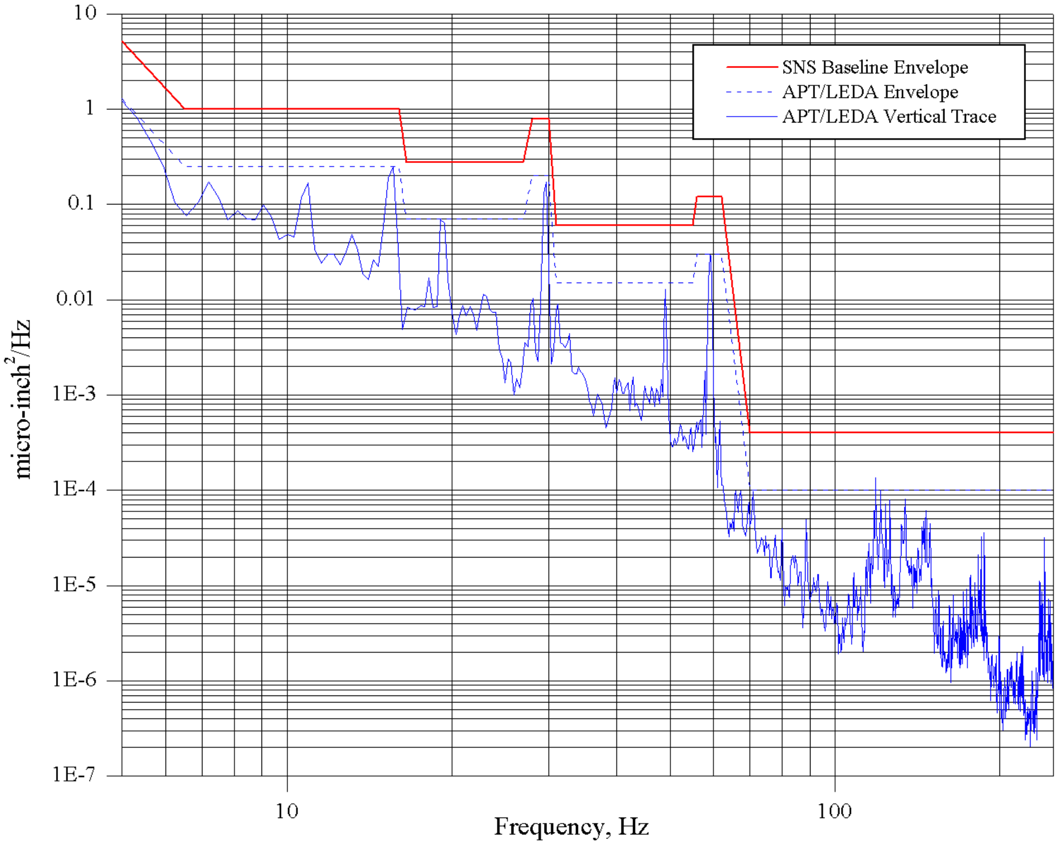
SNS-03

DTL Vibratory Environment

- **Broadband vibratory environment is always present**
  - Numerous Sources
    - » coolant pumps, coolant flow, vacuum pumps, HVAC equipment, sump pumps, facility air compressors
    - » Lorentz forces
    - » Auto, truck, and rail traffic
    - » Nearby construction, industrial activity
    - » Flowing surface & subsurface water, wind
    - » Background seismic activity
- **Vibratory motion of drift tubes with internal PMQs or EMQs can have deleterious effects on beam quality**
  - Single stem large drift tubes are susceptible to significant dynamic motion

SNS Accelerator
Estimated Baseline Vibratory Environment

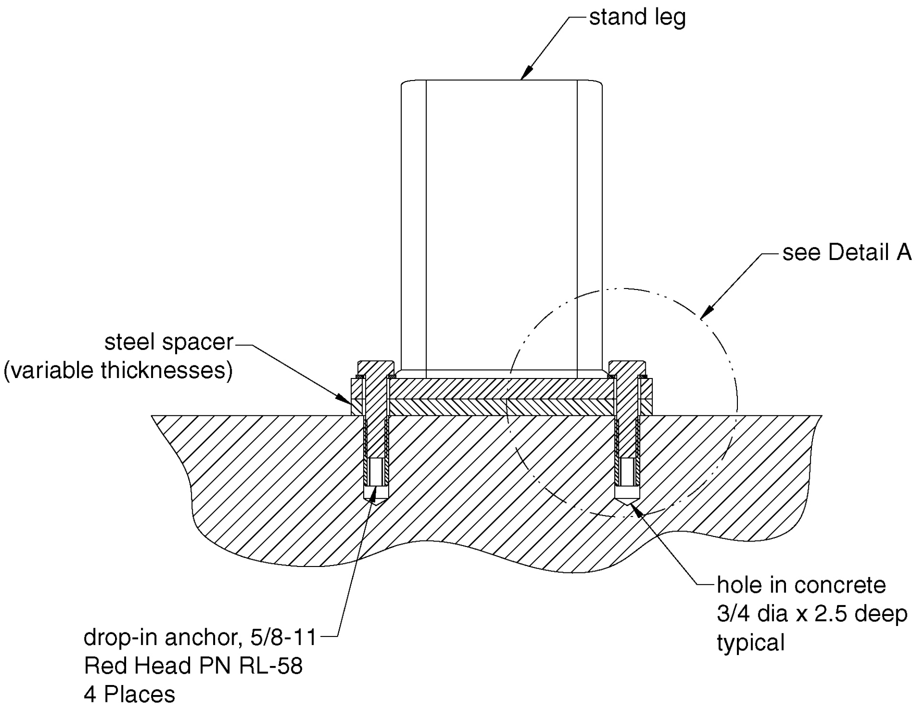
SNS baseline spectrum RMS displacement = 4.6 micro-inches
APT/LEDA spectrum envelope RMS displacement = 2.3 micro-inches

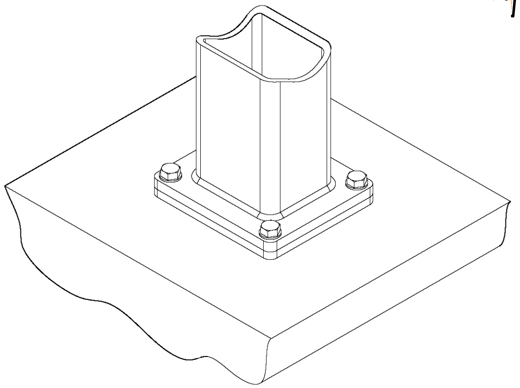


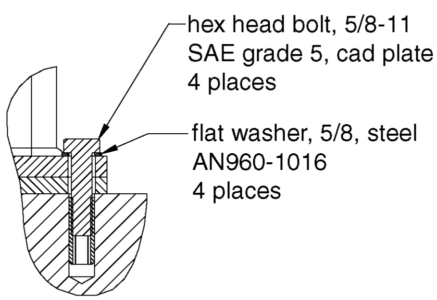
Design Approach

- **Minimize DTL Hardware Response**
  - Maximize System Mechanical Resonant frequencies
    - » Maximize accelerator support structure stiffness
    - » Minimize mass
    - » Incorporate very rigid connections to facility floor
  - Increase mechanical damping where feasible
    - » Bolted joints
    - » Damping enhancing coatings
- **Mitigate Facility Vibratory Sources**
  - Appropriately Isolate all rotating/reciprocating machinery
    - » Incorporate conventional vibratory isolation mounts
    - » Incorporate non-rigid plumbing connections to all pumps
    - » Maximize distance to accelerator
  - Specify appropriately balanced rotating machinery
  - Minimize use of non-essential mechanical equipment during accelerator operation
    - » Sump pumps
    - » HVAC equipment
    - » Forklifts
  - Minimize high velocity fluid flow

Support Stand Floor Interface

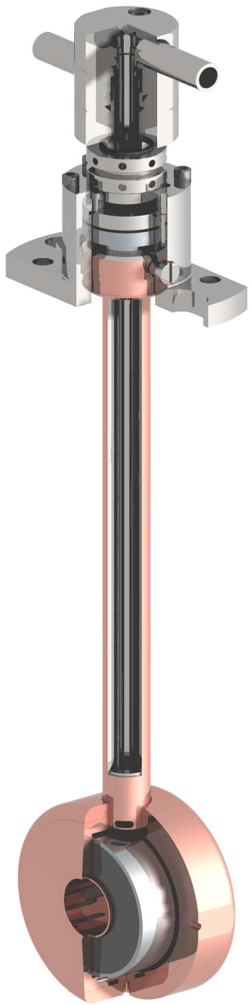


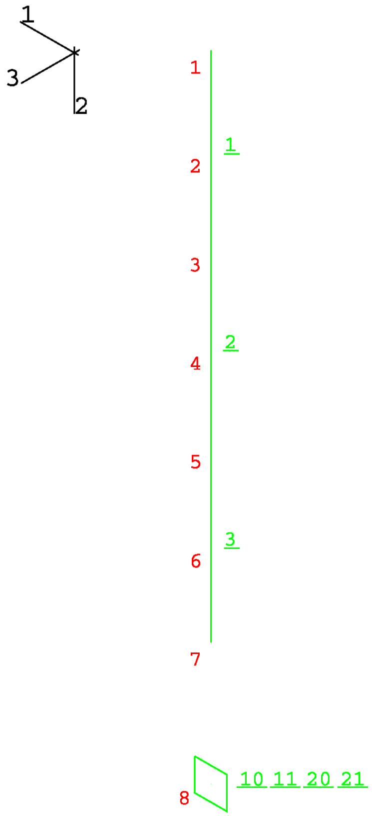




Detail A

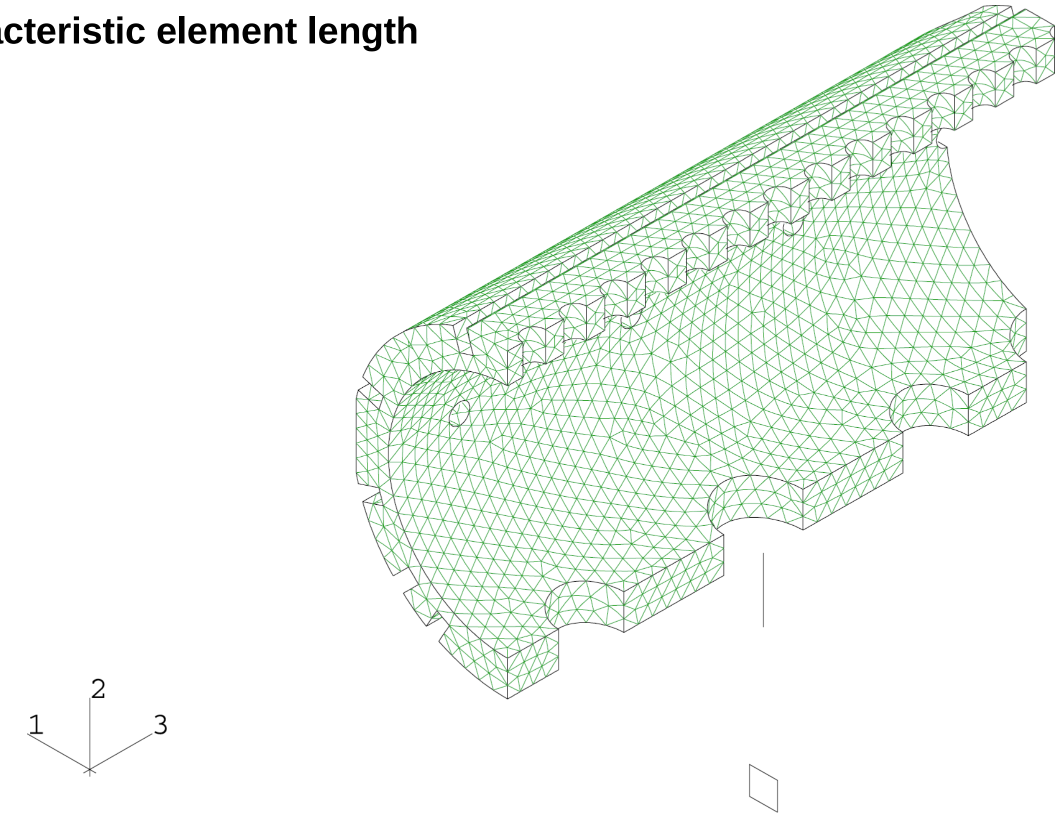
Drift Tube & Stem Dynamic Modeling





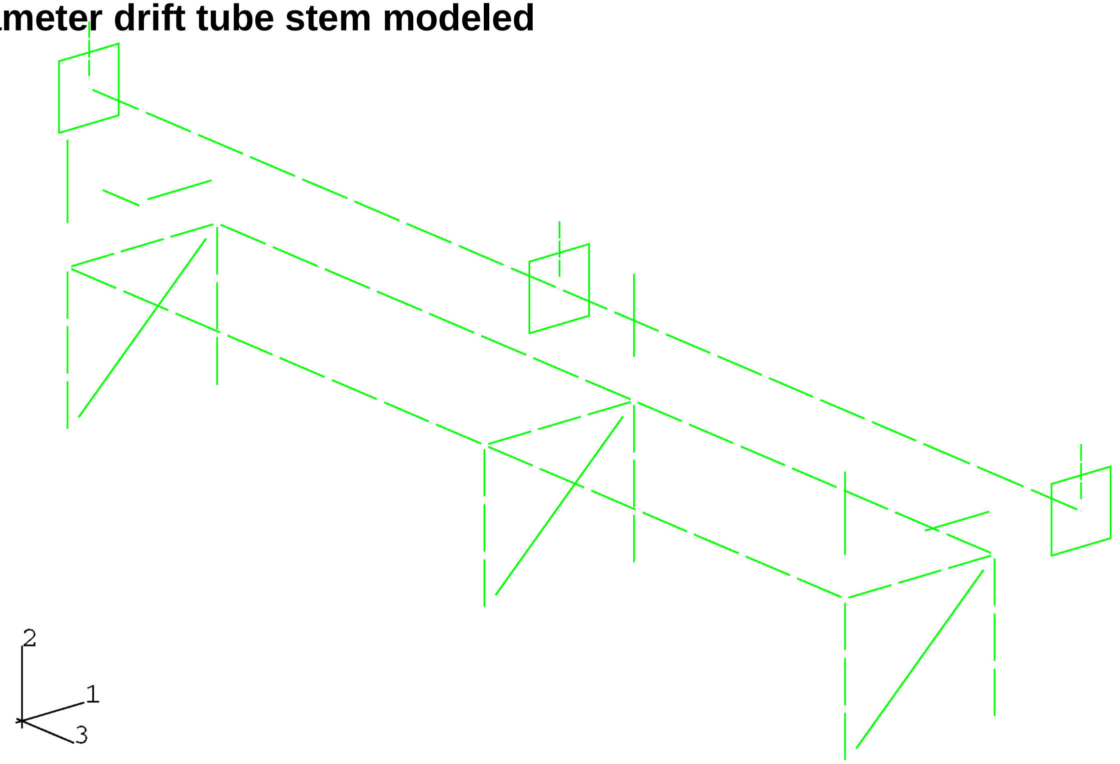
DTL Tank FE Mesh

- DTL tank #1a ¼ symmetry FE model
- 24,000 10 node tetrahedral elements
- 1.38 inch characteristic element length

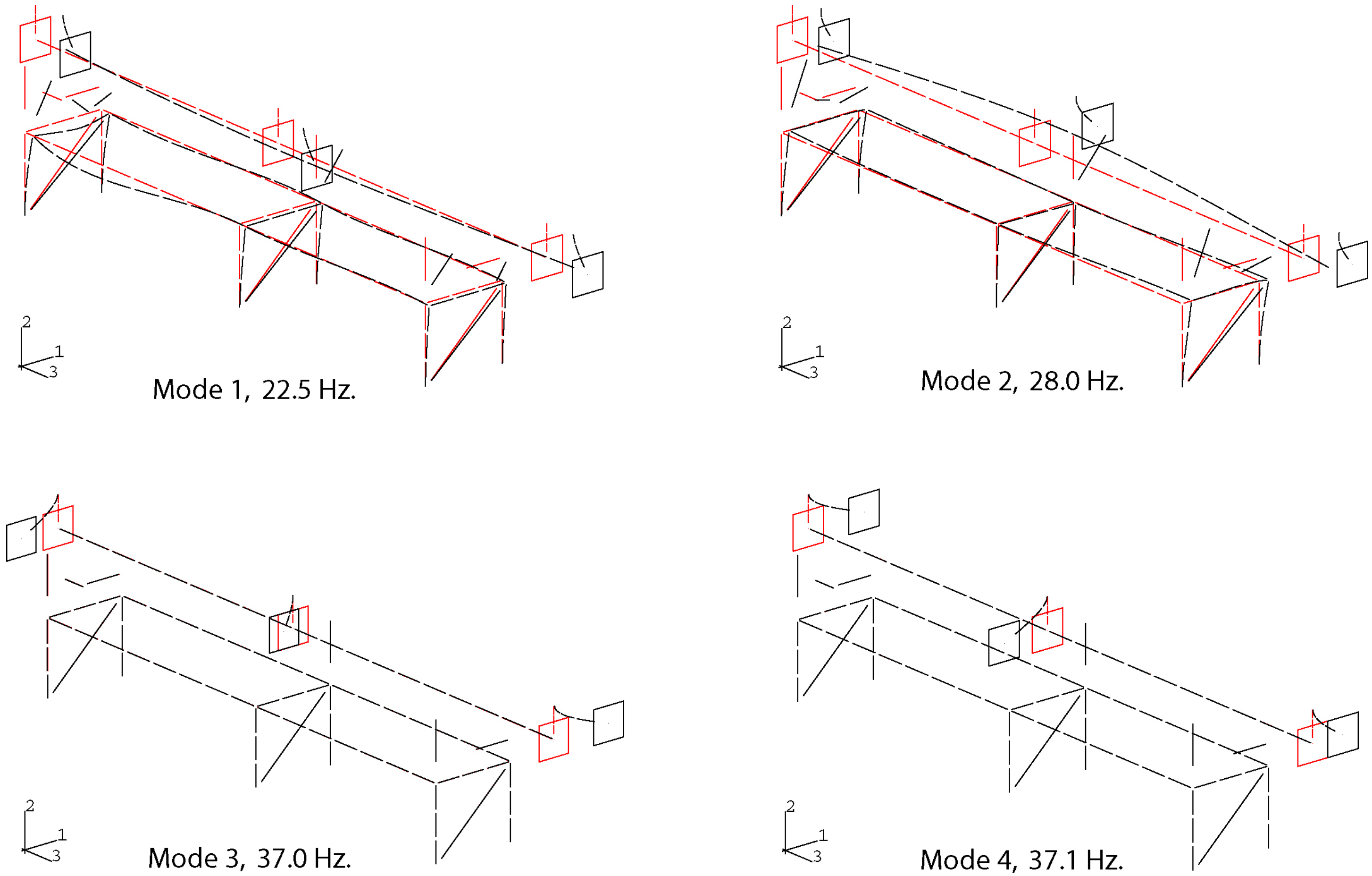


DTL Tank #2 Assembly Dynamic Modeling

- Quadratic beam elements represent DTL and support structure
- Mass and rotary inertia elements represent drift tube bodies & magnets
- 6 support links represented with 2 node truss elements
- Accurate mass representation of DTL tank and ancillary hardware
- 0.75 inch diameter drift tube stem modeled



DTL Tank #2 Assembly
Dynamic Mode Shapes & Frequencies



Calculated Drift Tube RMS Dynamic Motion

- **DTL Tank #2 assembly**
- **Combined x, y, and z axis base excitation**
- **½% structural damping (conservative)**

	RMS Displacement		
Drift tube	**x axis**	**y axis**	**z axis**
first	124 μ-in	24 μ-in	85 μ-in
~ middle	200 μ-in	10 μ-in	85 μ-in
end	148 μ-in	46 μ-in	86 μ-in

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Support Structure

Design and Analysis

Steve Ellis, Matt Fagan, Tom Ilg

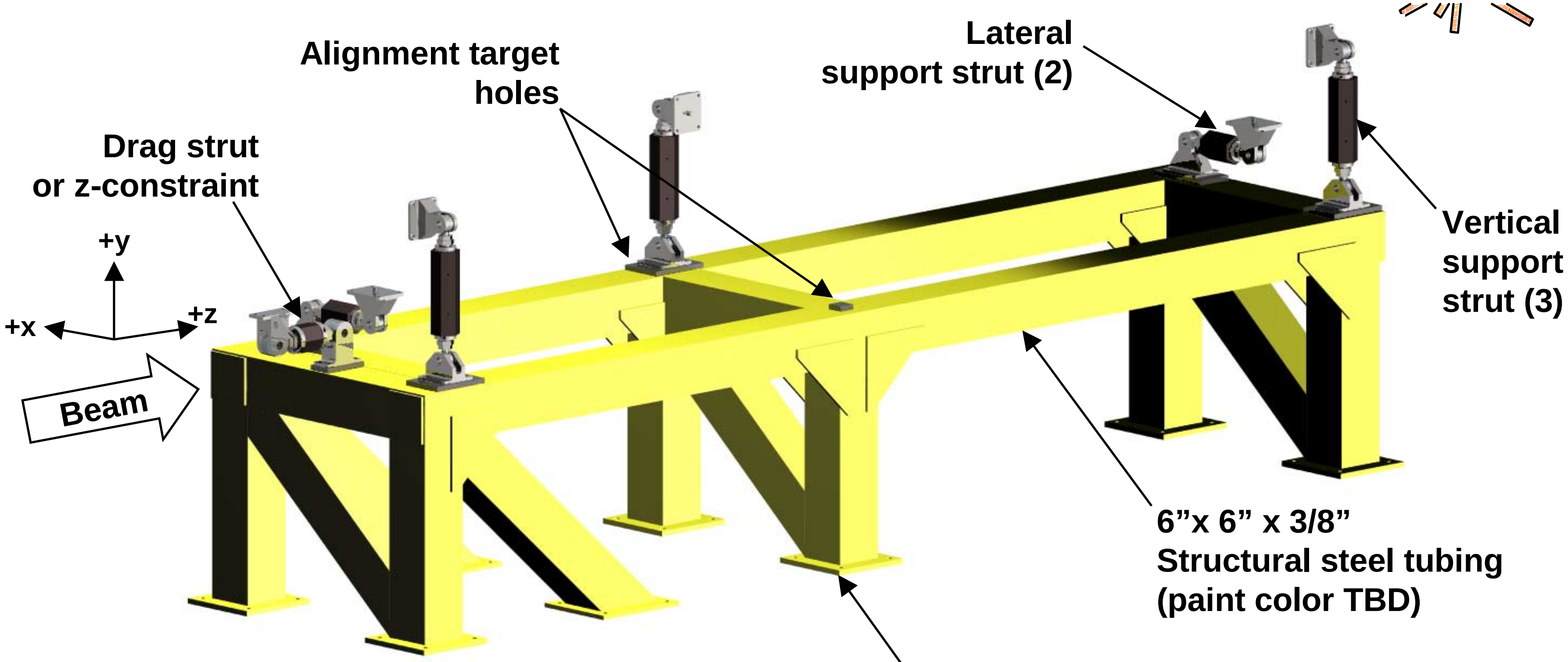
DTL Support Structure Functions

- Provides support for the DTL tanks and sub-systems.
- Provides seismic restraint.
- A kinematic 6-strut support system (3 vertical struts, 2 lateral struts , and 1 axial strut) provides 6 degrees of freedom adjustment for proper alignment to accelerator coordinate system.
- Provides ±.50” xyz fine adjustment at the DTL tanks using differential threads and ± 1.00”(in y direction) course adjustment at the floor using spacer plates.
- Provides open access for vacuum pump maintenance.

DTL Support Structure Requirements

- **Drift tube stability criteria.**
  - TBD µ-inch transverse RMS.
- **PSD data based on APT LEDA facility.**
- **Seismic input.**
  - 0.55g peak acceleration per DOE-STD-1020-94.
- **DTL tank alignment and position.**
  - ±.005” transverse.
  - ±.005 ” longitudinal.
- **Welded construction per AWS D1.1-2000.**
- **Structural steel tubing per ASTM A-500 grade B.**
- **Allowable stresses for structural elements not to exceed $0.3F_{ty.}$**

Support Structure Layout

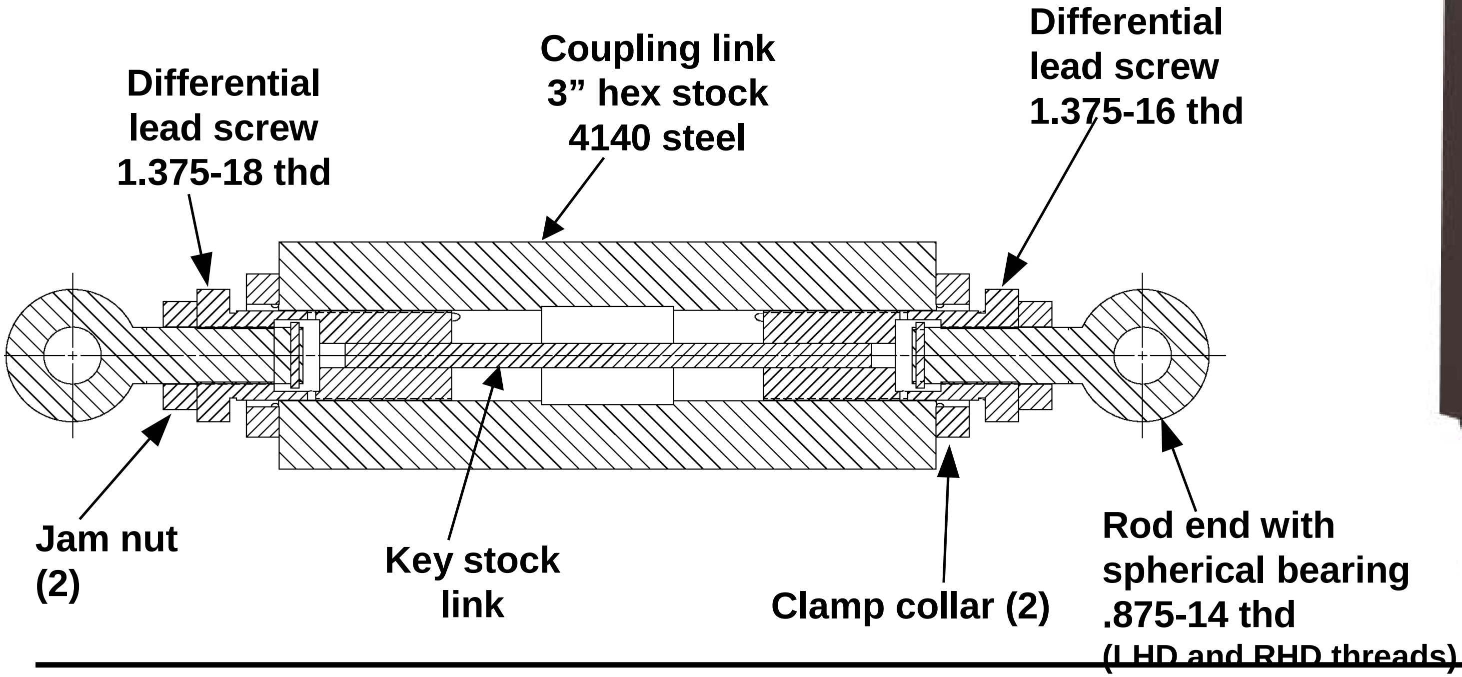


Advantages of a 6-strut support system

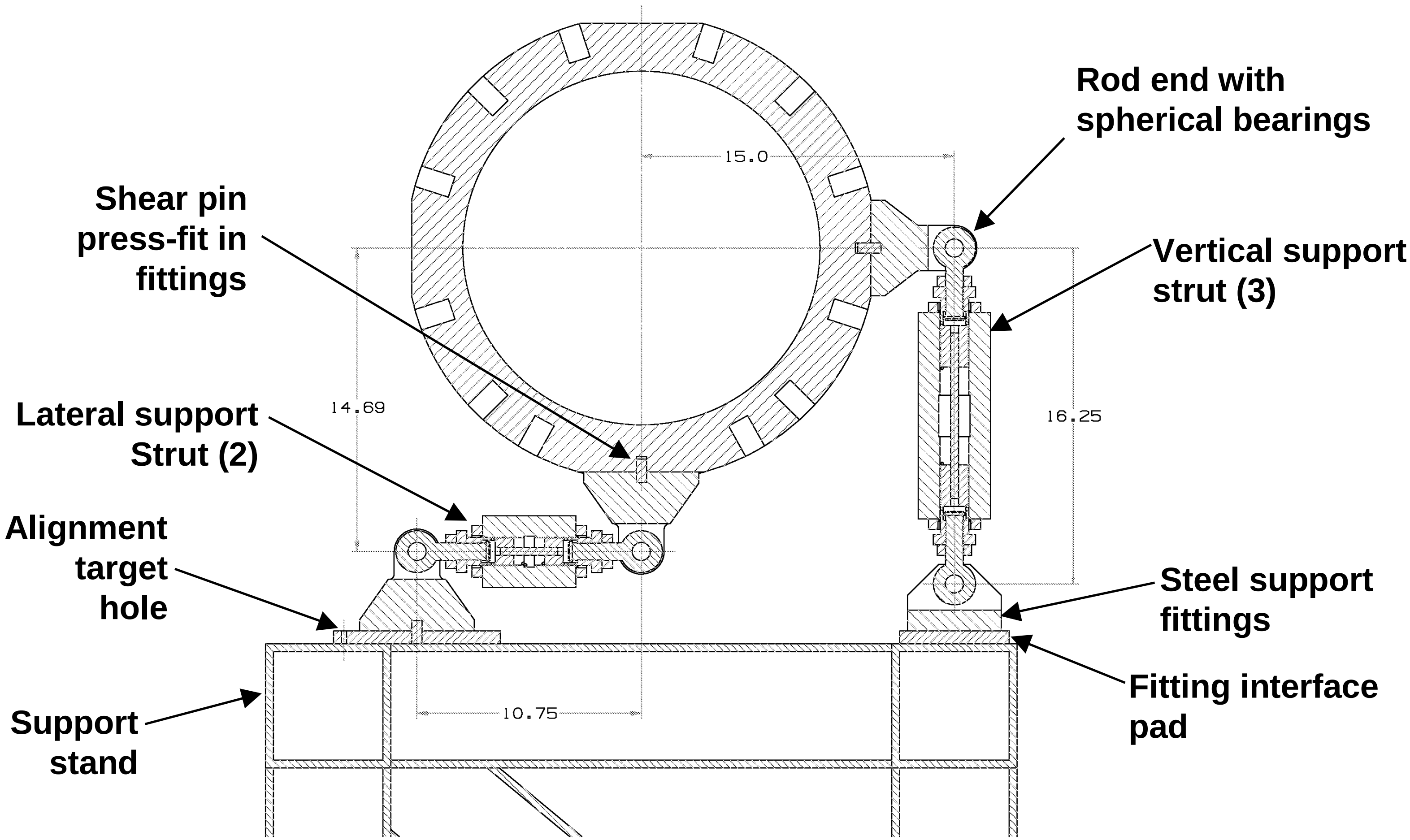
- Avoids an overstrained system
- Little or minimal coupling between axes
- Allows relatively easy adjustment

Typical Strut Design

- Rod end with spherical bearings.
- .007"per turn fine adjustment capability using differential threads, 1.375"-16 and 1.375"-18 threads.
- .070"/turn course adjustment capability.
- ±.50" total travel.
- Design is similar to the APT LEDA support links.

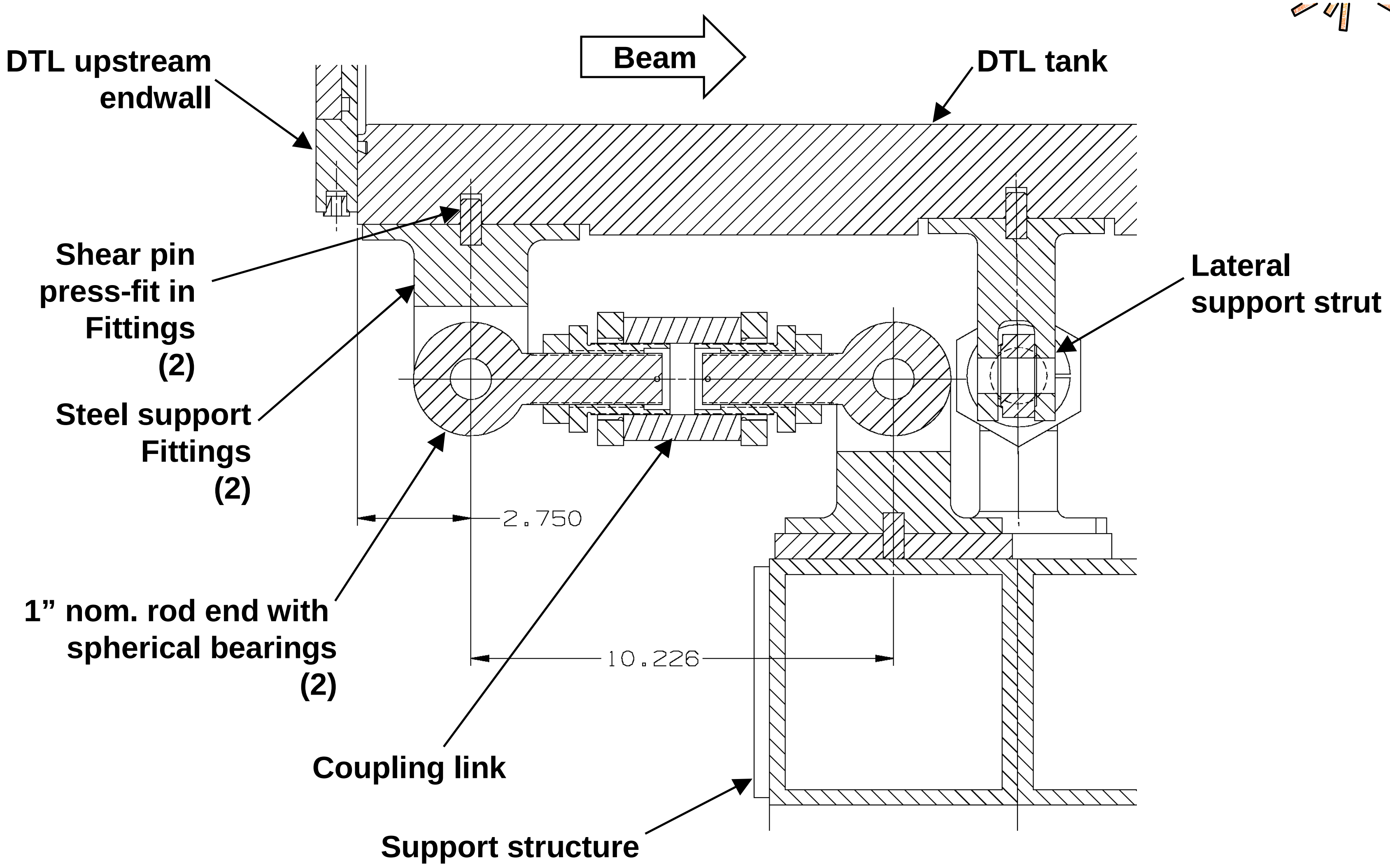


Support Strut Design

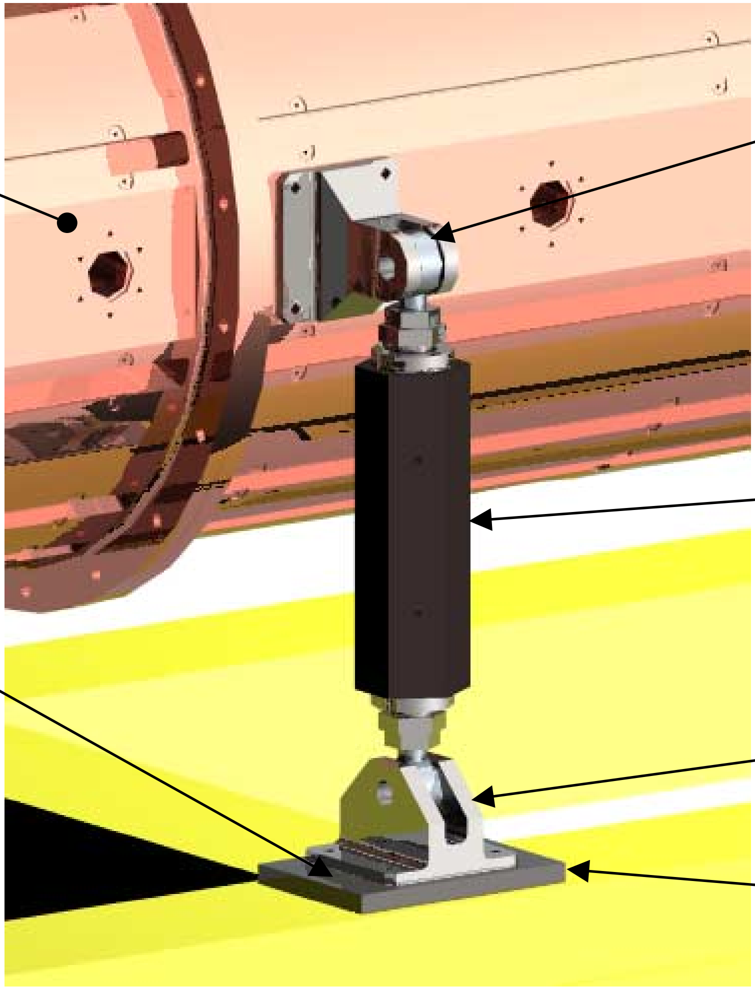


View looking downstream

Drag Support Strut



Support Struts



DTL tank

Rod end with spherical bearings (2)

Coupling link
3” hex stock
4130 steel
black anodized
finish

Alignment target hole

Steel support fittings

Fitting interface pad welded to stand

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Support Stand Structural Analysis

Matt Fagan

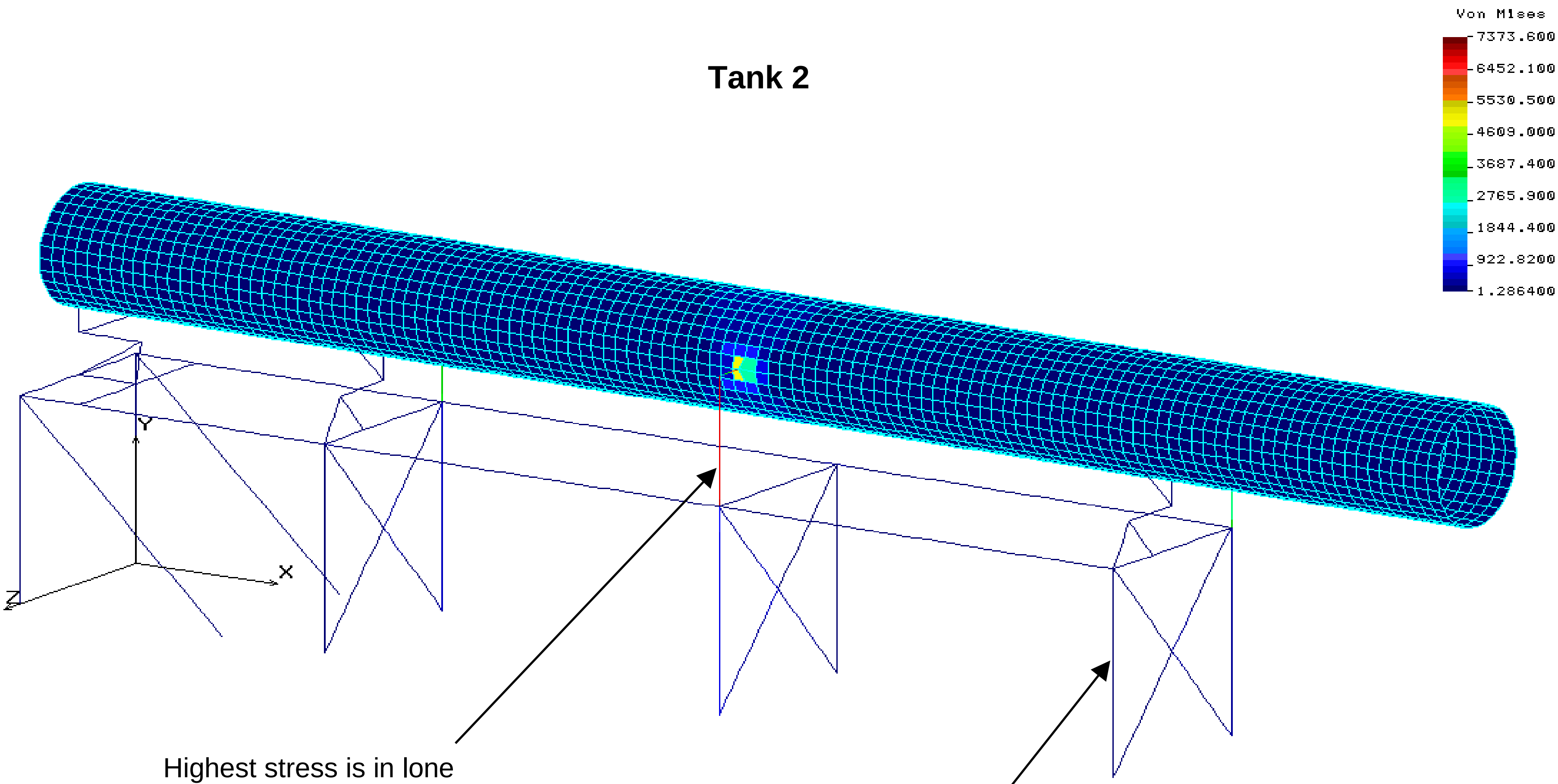
Vertical Support Struts - Three vs. Six

- **Three vertical strut arrangement is used (instead of six strut arrangement).**
- **Advantages**
  – Not overconstrained. Adjustment easier since strut loads not monitored, fewer to adjust, adjustment algorithm easier.
  – More open space around tank for components, and better access.
  – Cost savings / fewer parts
- **Disadvantages**
  – Vertical struts must be enlarged to regain stiffness - Not a problem.
  – Stresses higher in vertical struts - Enlarged struts offset increased loads - Same stress.
- **Vertical struts moved inboard where possible to increase tank fundamental frequency. Struts located near quarter points.**

DTL Static Loadings - Gravity Only

- DTL tank is supported by three vertical struts.   Lateral and drag struts not loaded.
- Load transferred to legs located directly under struts, and down to floor.
- Struts and strut brackets encounter the highest stresses (smallest cross sections).
- Stress in lone vertical strut at limiting cross section is 11,800 psi. Struts will be enlarged to increase stiffness and structure natural frequency. Stress will be reduced.
- Bracket design not finalized.   Will be optimized for strength and stiffness.

COSMOS Model - Gravity Loading



Highest stress is in lone vertical strut (11,800 psi)

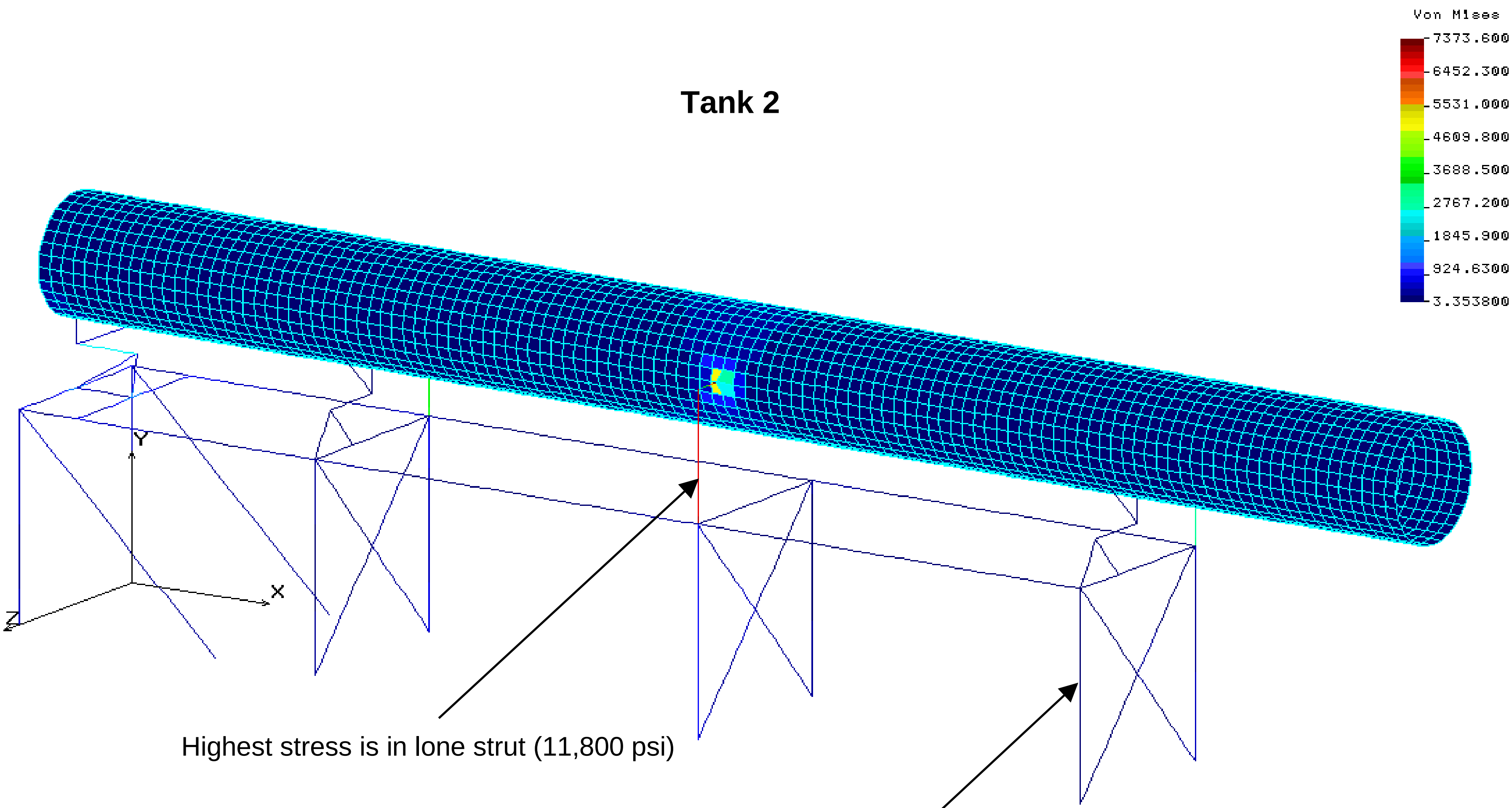
Strut ends are pinned connections

Frame experiences low stress

DTL Static Loadings - Gravity / Vacuum

- Gravity loads present, plus following…………….
- Support structures react vacuum loading that tends to push the tanks towards each other, given large diam. bellows between tanks. Vacuum load on each tank is 4050 lb.
- Load is reacted by drag strut, which transmits the load through frame and to floor. Lateral struts not loaded.
- Stress in drag strut at limiting cross section is 3,800 psi. Strut will be enlarged to increase stiffness and structure natural frequency. Stress will be reduced.
- Drag strut bracket design not finalized. Will be optimized for strength and stiffness.

COSMOS Model - Gravity and Vacuum Loading



Highest stress is in lone strut (11,800 psi)

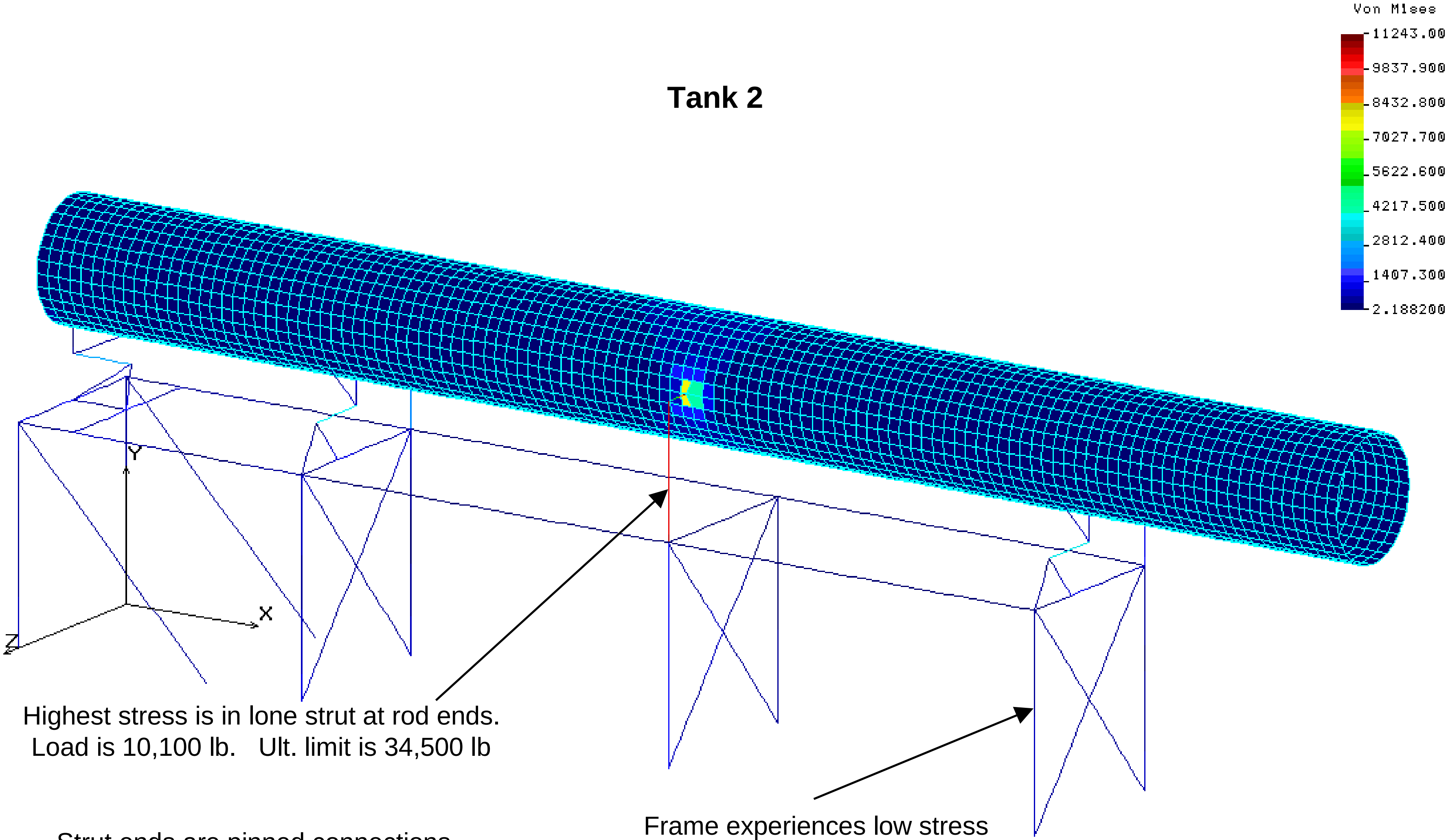
Frame experiences low stress

Strut ends are pinned connections

DTL Static Loadings-Gravity/Vacuum/Seismic

- Gravity and vacuum loads present, plus the following ………
- Seismic loading treated as 0.55 G in any lateral direction.
- Beam direction seismic event adds to, or subtracts from, the vacuum load on tank. Stress in drag strut limiting c.s. is 9,400 psi, total.
- Across beam seismic event loads the lateral struts. Stress in lateral struts is 5,900 psi. Load in lone vertical strut is 10,100lb. (limit = 34,500 lb). Struts will be enlarged to increase stiffness and structure natural frequency.
- Stand is anchored to the floor with concrete anchors.

COSMOS Model - Gravity / Vacuum / Seismic



Highest stress is in lone strut at rod ends.
Load is 10,100 lb. Ult. limit is 34,500 lb

Frame experiences low stress

Strut ends are pinned connections

DTL Tanks

- **Vacuum Effects on Tank Alignment - Tanks connected by a large diam. bellows. A 4100 lb vacuum force pushes tanks together. Support structure must react this force. Maximum stress is low (drag strut). Translation of tank is 0.003 inches, which can be compensated for.**

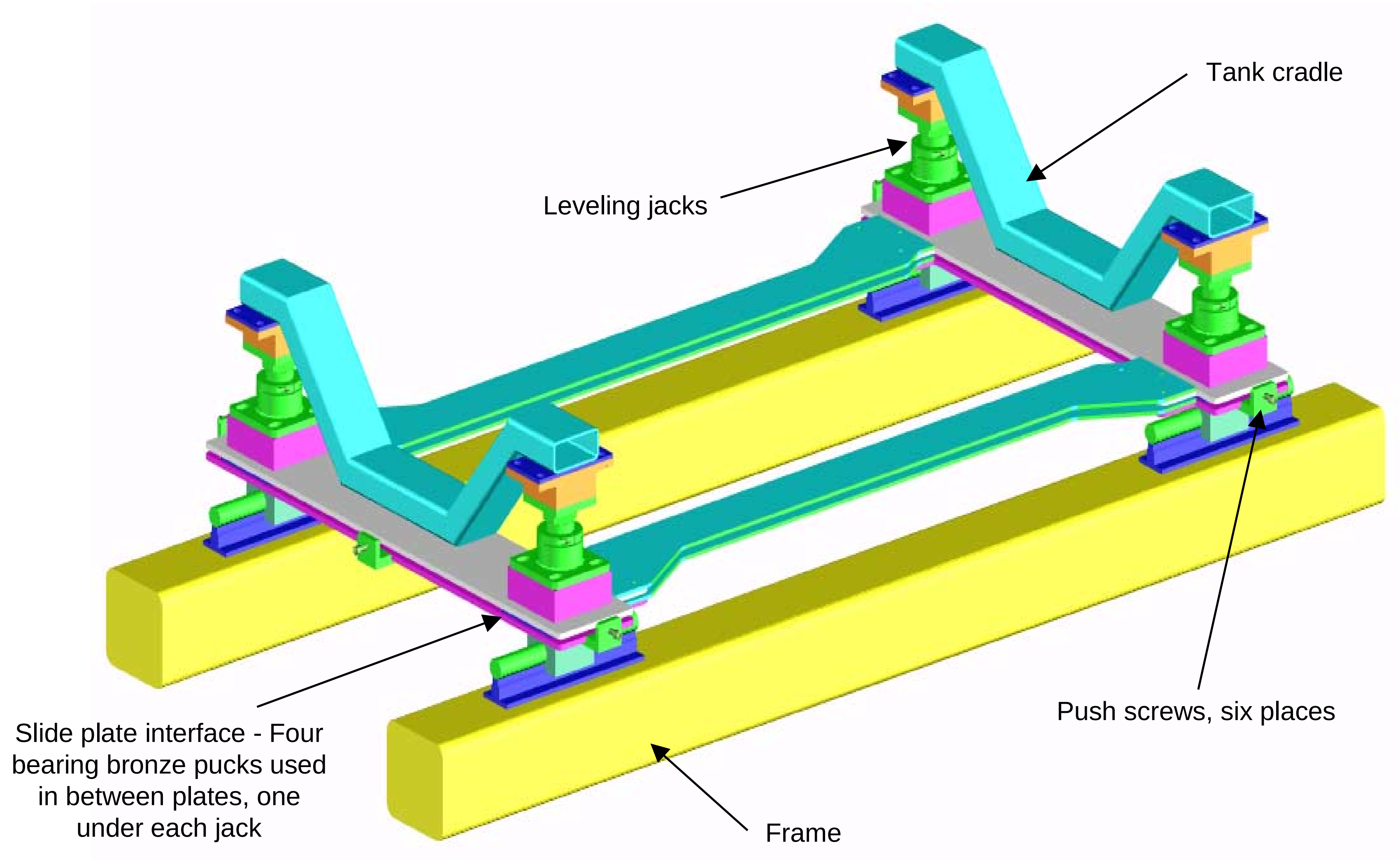
- **Tank Thermal Expansion Considered - A 10°F uniform temperature rise is used, which causes tank to expand. Beam direction tank expansion alters the six strut support system slightly. Misalignment effects are less than 0.000008 inches.**

- **Iris Effects Considered - The effects of the iris/waveguide being supported off of the tank are considered. Stresses in the tank and the loaded hardware are low, and factors of safety of 6+ result.**

DTL Tank Installation Device

- **Device allows tank sections to be brought together slowly and precisely to prevent damage to interface parts.**
- **Individual parts are lightweight, to aid assembly/disassembly.**
- **Device provides for fine adjustment in all six degrees of freedom.**
- **Device does not interfere with DTL components.**
- **Crane not used for final placement - increased technician safety.**

DTL Tank Installation Device



Future Tasks

- **Optimize brackets at ends of support struts.**
  - Minimize stress
  - Maximize stiffness
  - Large “footprint” on tank
- **Iris waveguide - tank interface components**
- **Intertank hardware**
- **Further optimization of support struts**
- **Assembly / Transportation Loads**

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DTL Interfaces

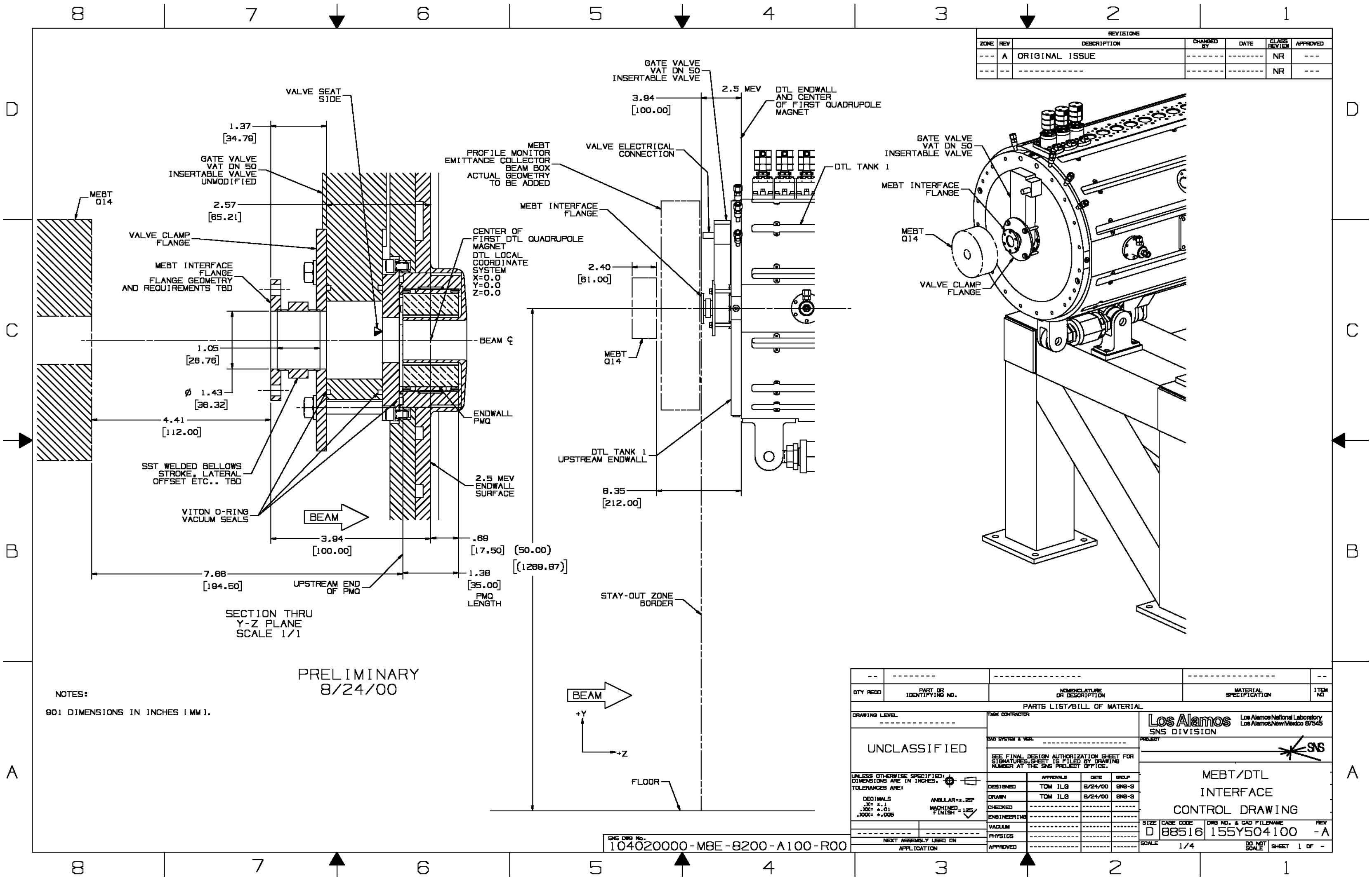
MEBT, 402.5 MHz window, CCL, Intertank regions, and Diagnostics

Tom Ilg

Outline

- MEBT interface
- Intertank regions
- CCL interface
- 402.5 MHz window
- Endwall valve

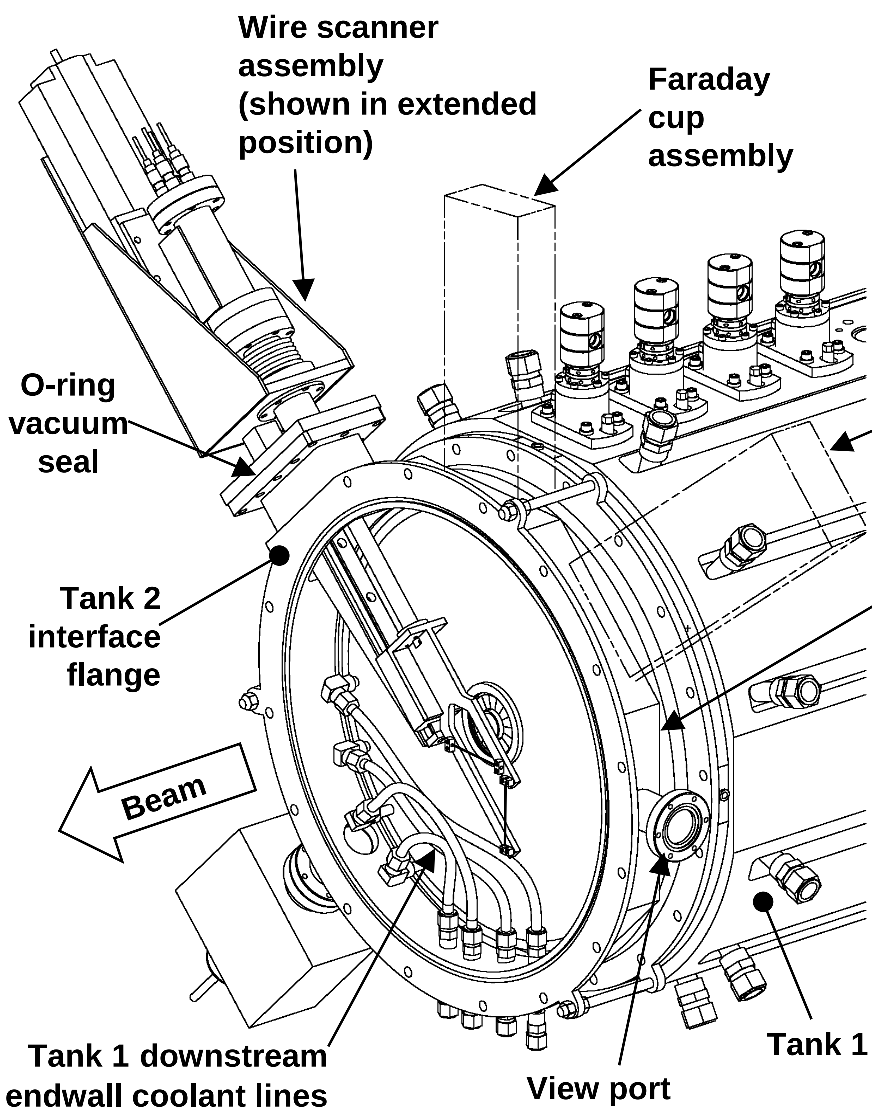
MEBT Interface Drawing

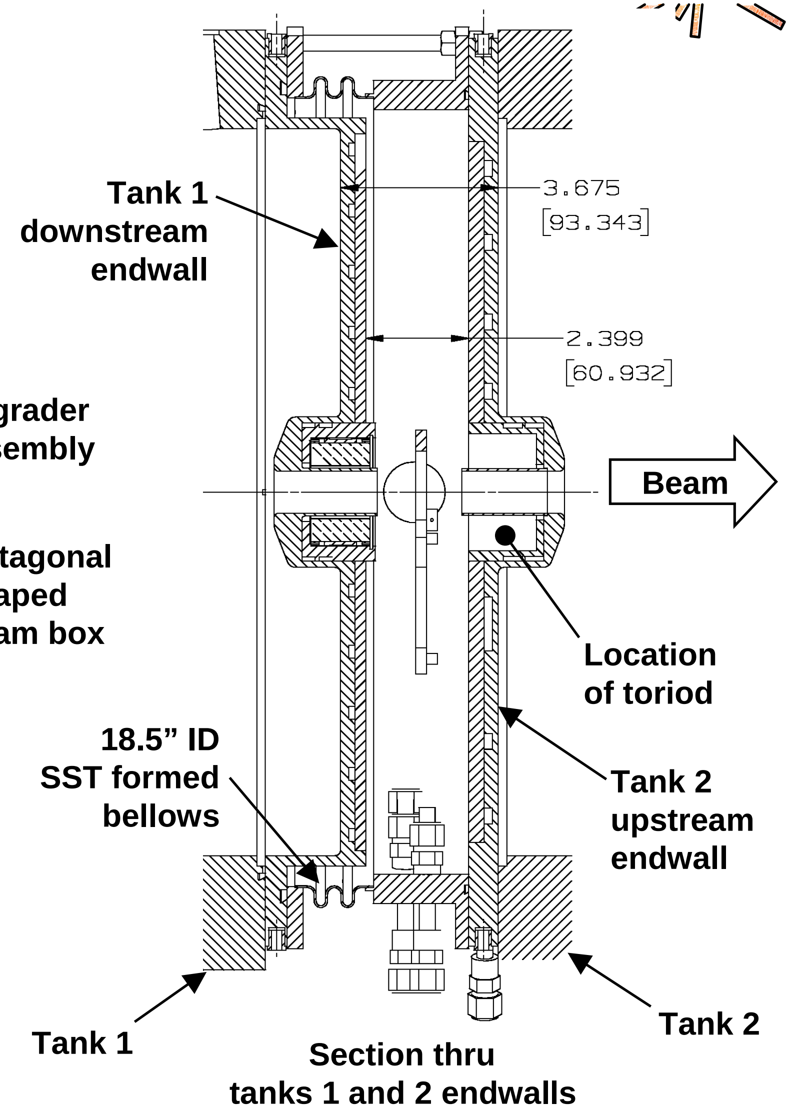


Intertank Regions

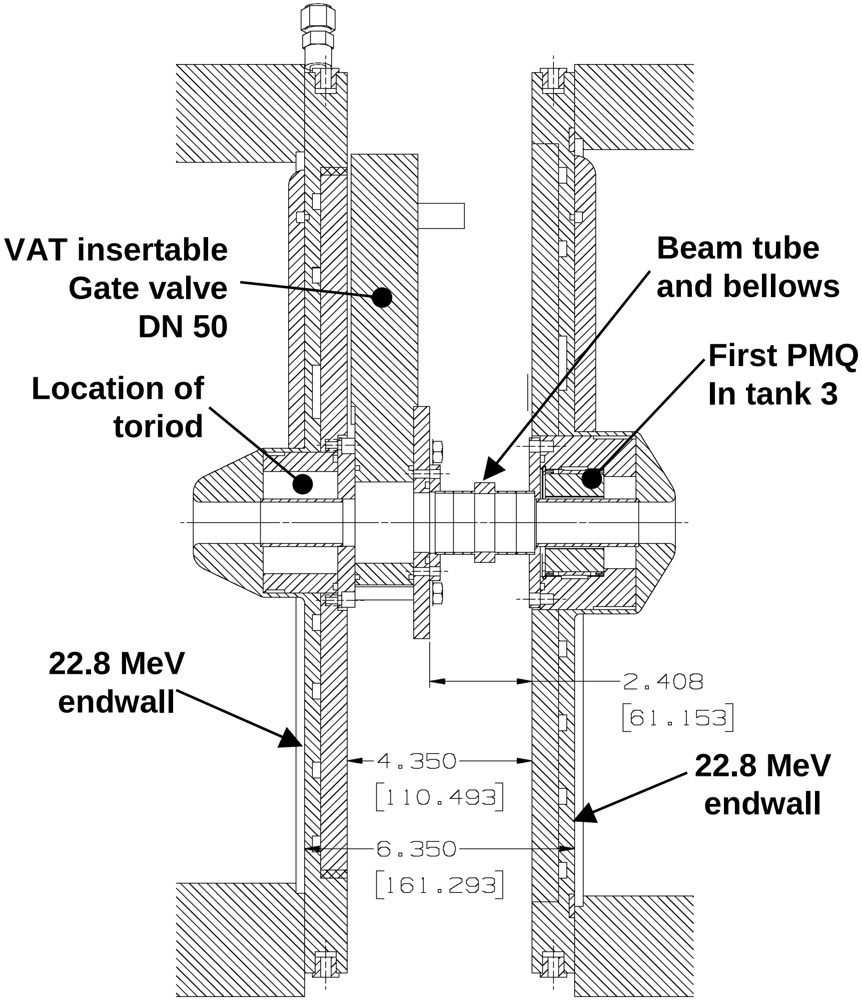
- **1 $\beta\lambda$ spacing between tanks.**
- **Distance between tank endwalls range from 3.675” to 10.900”.**
- **Components required to fit:**
  - Bellows for mechanical compliance.
  - Inline gate valve, where space is available.
  - Diagnostics.
    - » Wire scanner
    - » Faraday cup
    - » Energy degrader
    - » Toriod, located in endwalls where available
  - Vacuum chamber or beam box for diagnostics.
    - » Vacuum pumping requirements is under investigation, a small ion pump is likely
- **Packaging and layouts for the intertank regions are in progress.**
  - Tanks 1 and 2 intertank region is near completion

Tank 1 and 2 Intertank Region

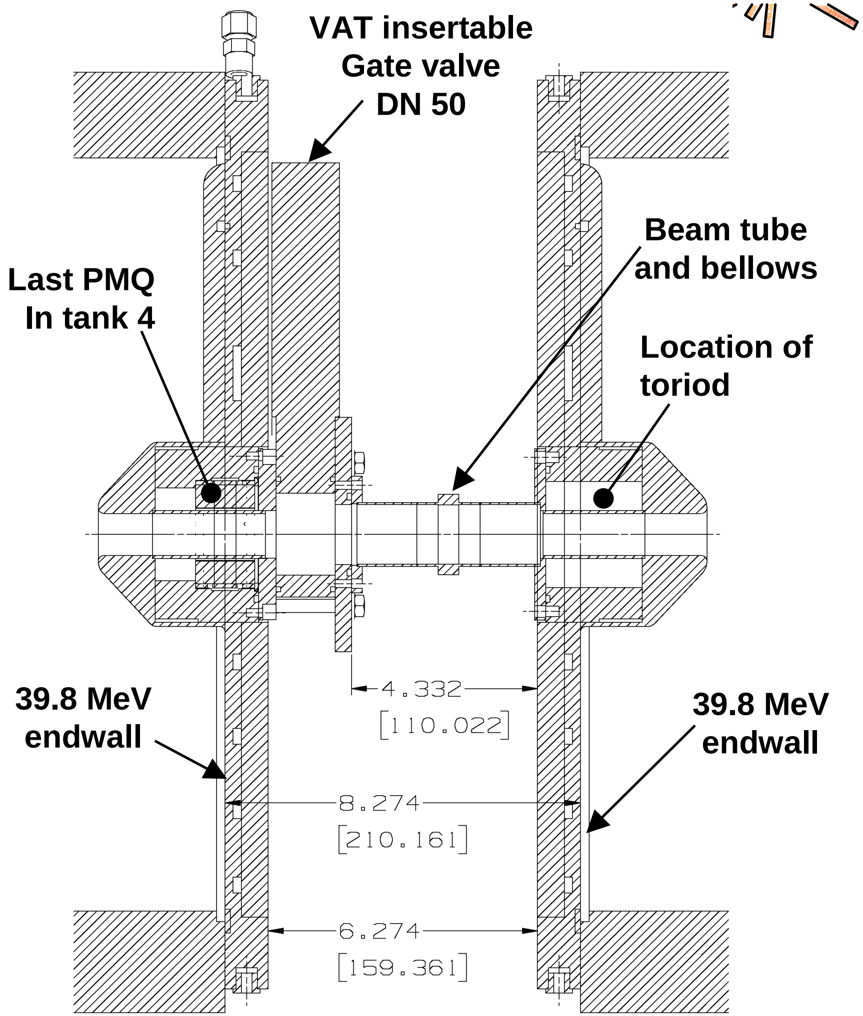




Intertank Regions (con't)

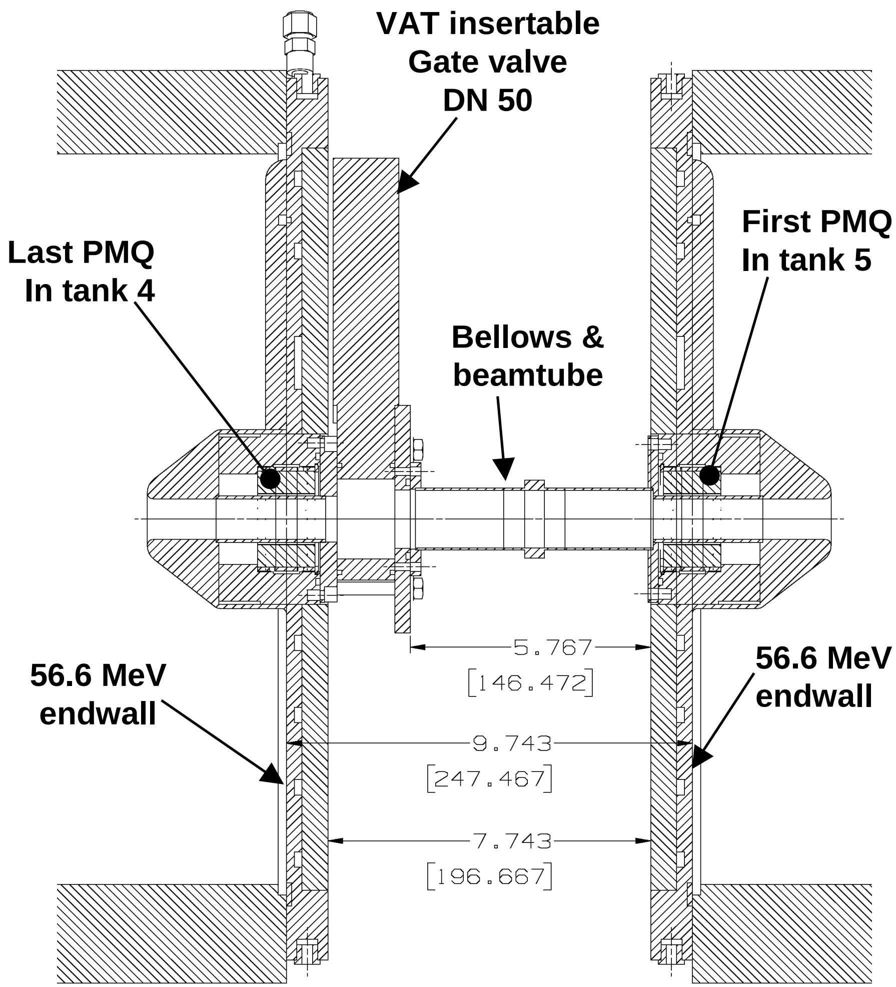


Tanks 2 & 3

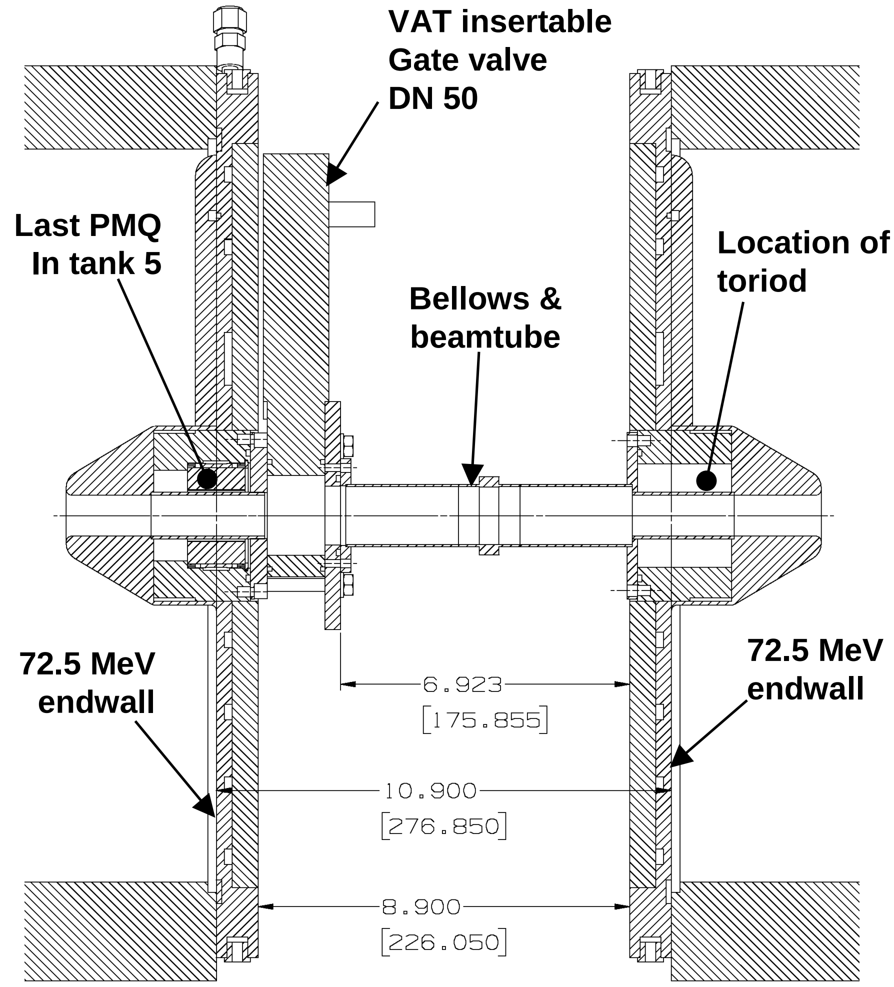


Tanks 3 & 4

Intertank Regions (con't)

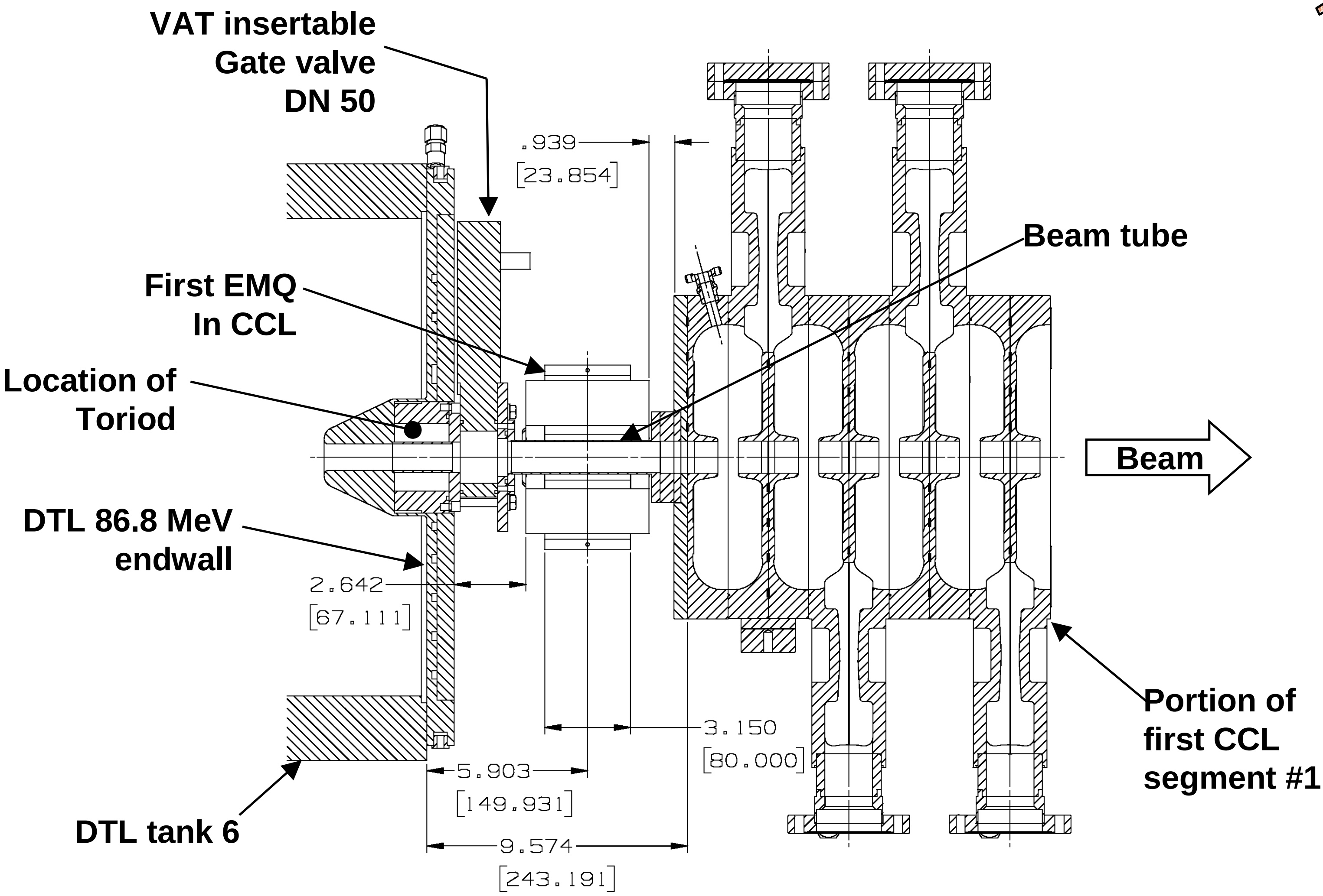


Tanks 4 & 5

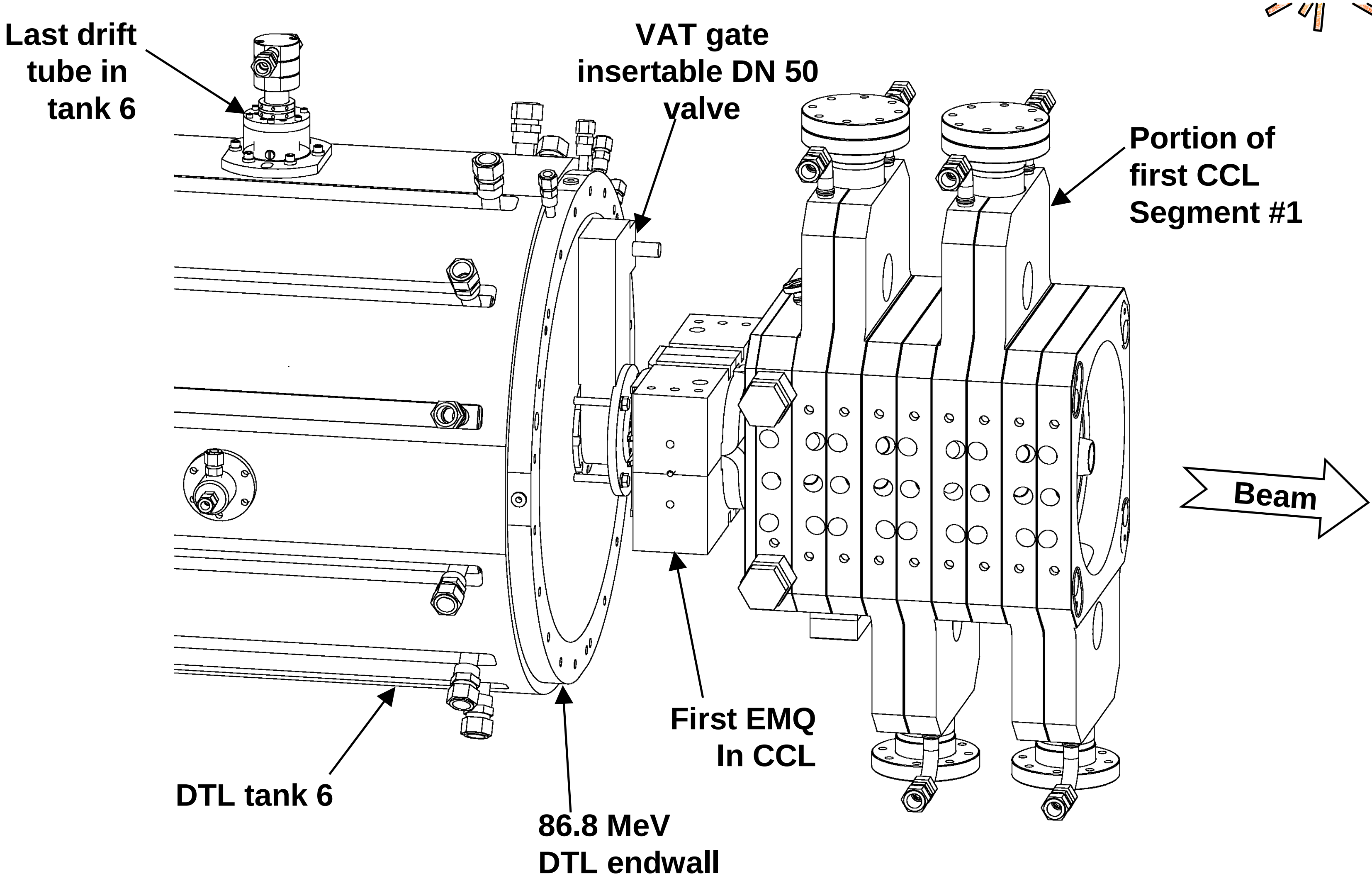


Tanks 5 & 6

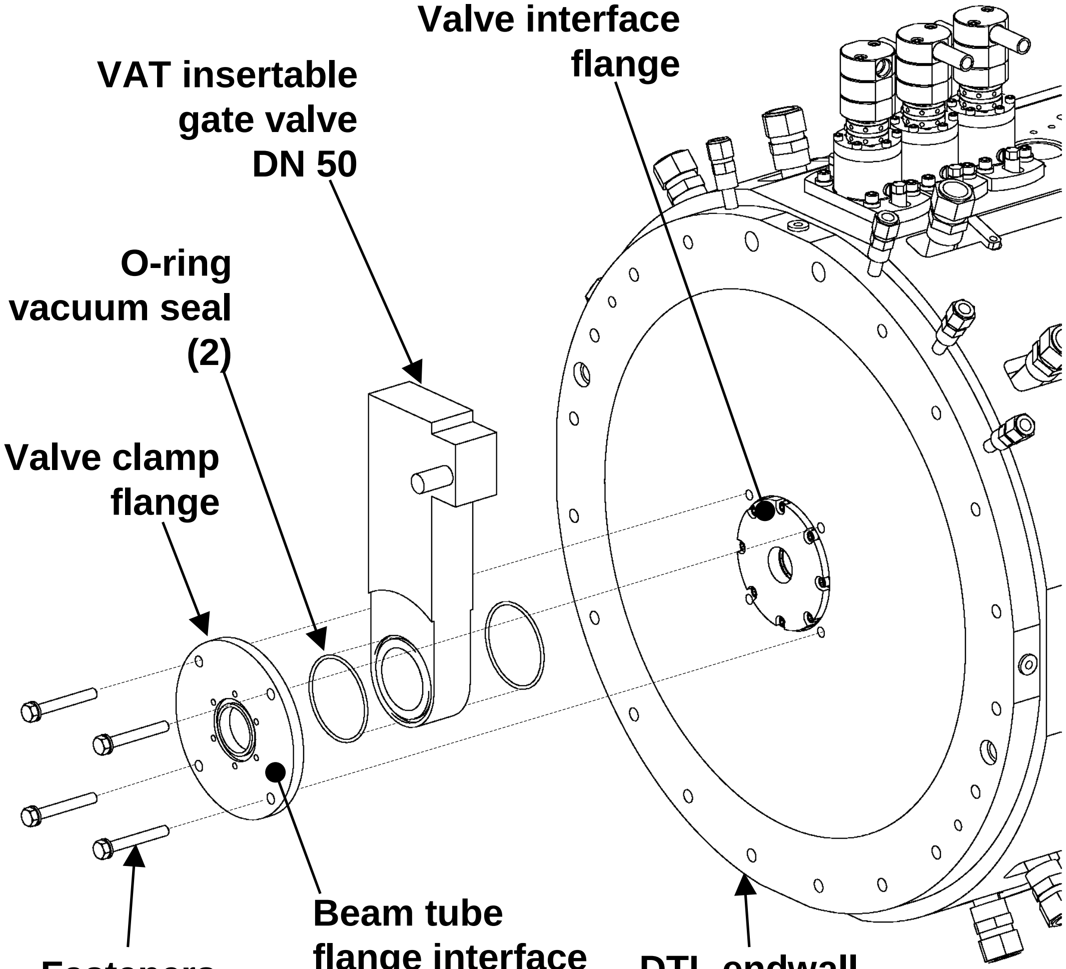
DTL CCL Interface



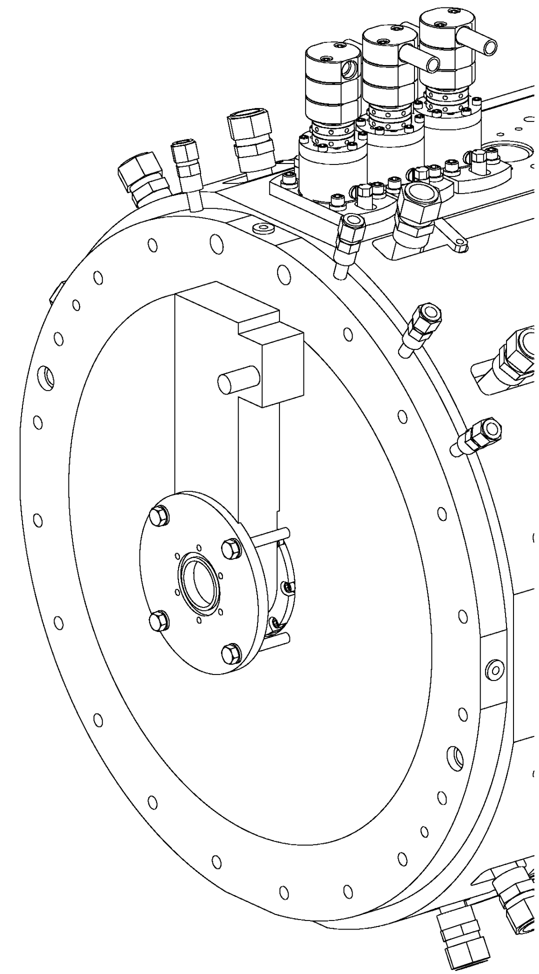
DTL CCL Interface (con't)



Typical Endwall Valve Installation

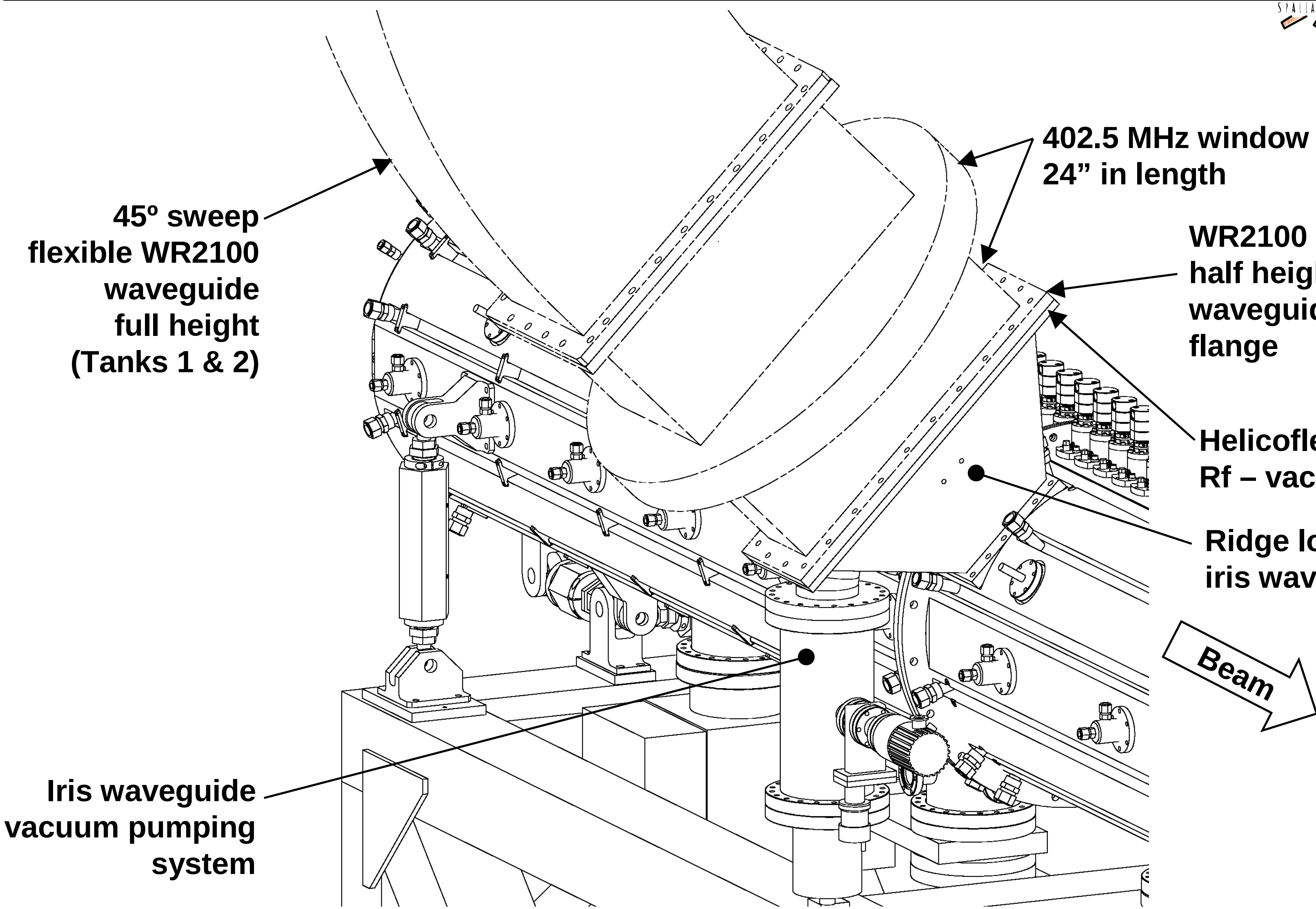


Exploded view



Un-exploded view

402.5 MHz Window Interface



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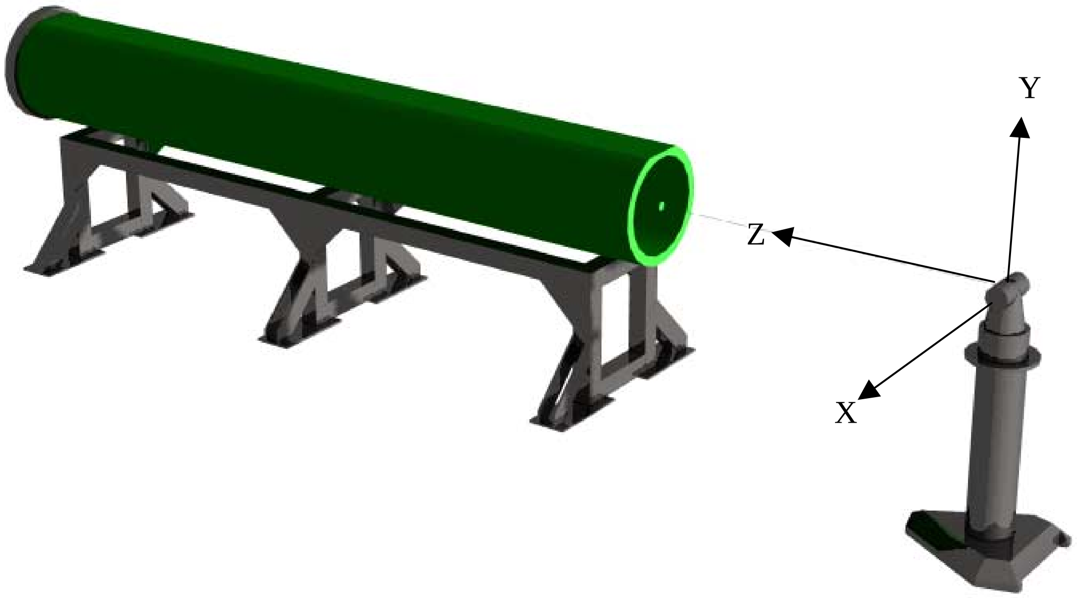
DTL ALIGNMENT

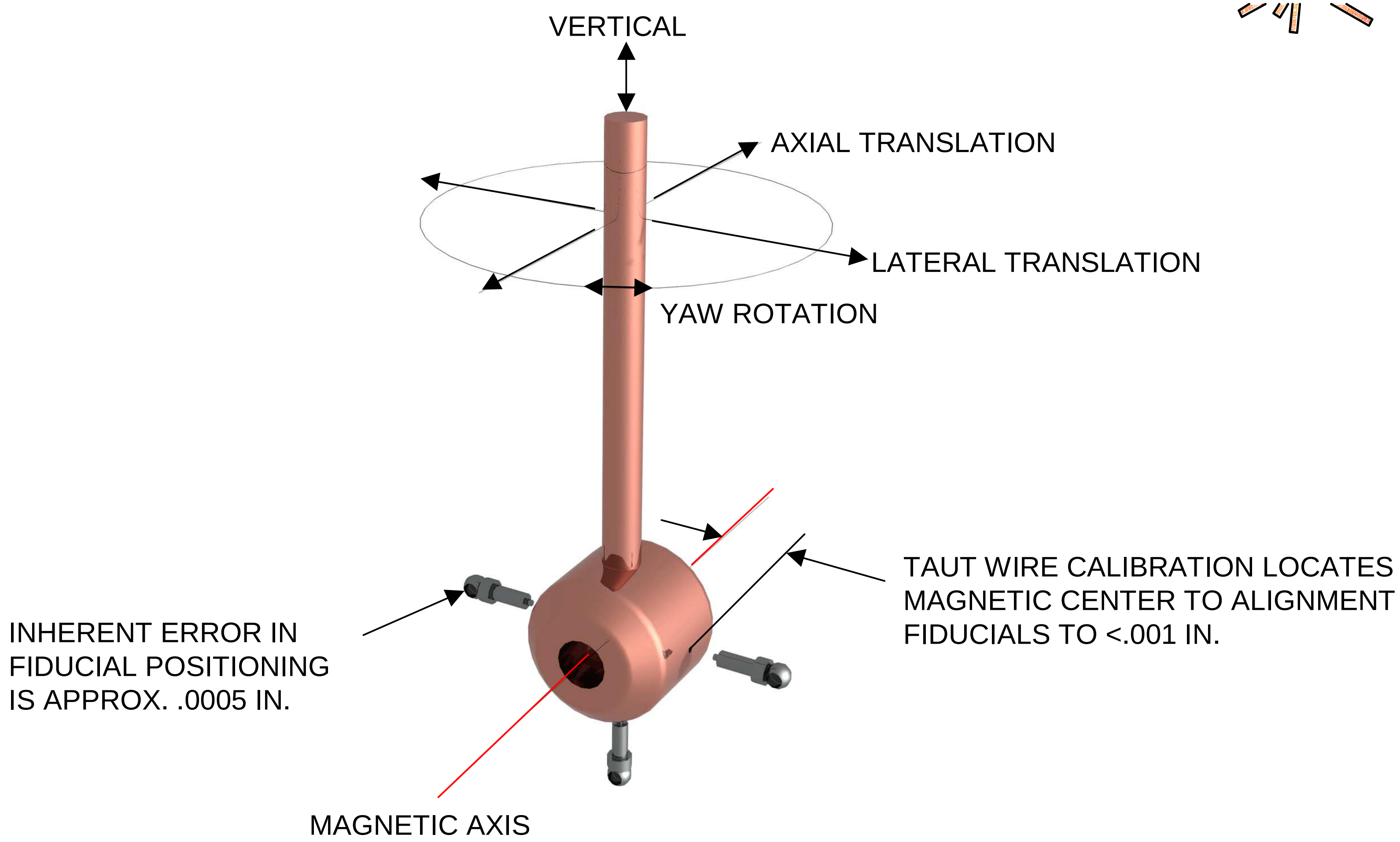
Bill Rodriguez

TOTAL DRIFT TUBE ALIGNMENT REQUIREMENT IS .005 INCH



LASER TRACKER MEASURES OBJECT CO-ORDINATES IN A DEFINED CO-ORDINATE SYSTEM

MAGNETIC CENTER IS KNOWN TO ~ .0015 IN



DRIFT TUBE ALIGNMENT PROCEDURE

- **Establish a global co-ordinate system for general reference**

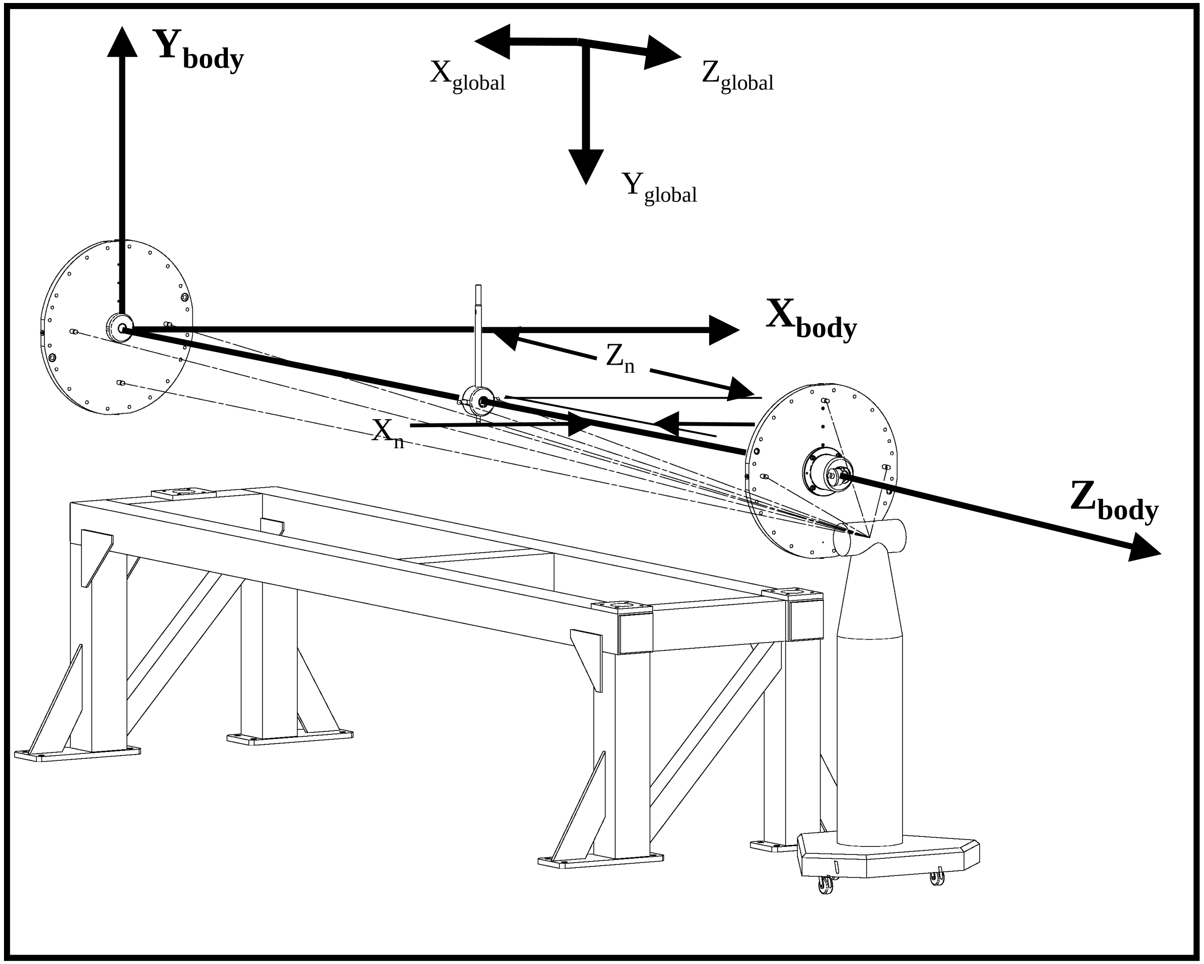
- **Establish a body co-ordinate system**
  - **1-Measure first endwall fiducials**
  - **2-Construct endwall plane and co-ordinate origin**
  - **3-Measure second endwall fiducials**
  - **4-Constuct point on Z axis**
  - **5-Construct body co-ordinate system**
  - **6-Remove second endwall**

- **Install 1st drift tube and measure fiducial co-ordinates relative to the body co-ordinate system**

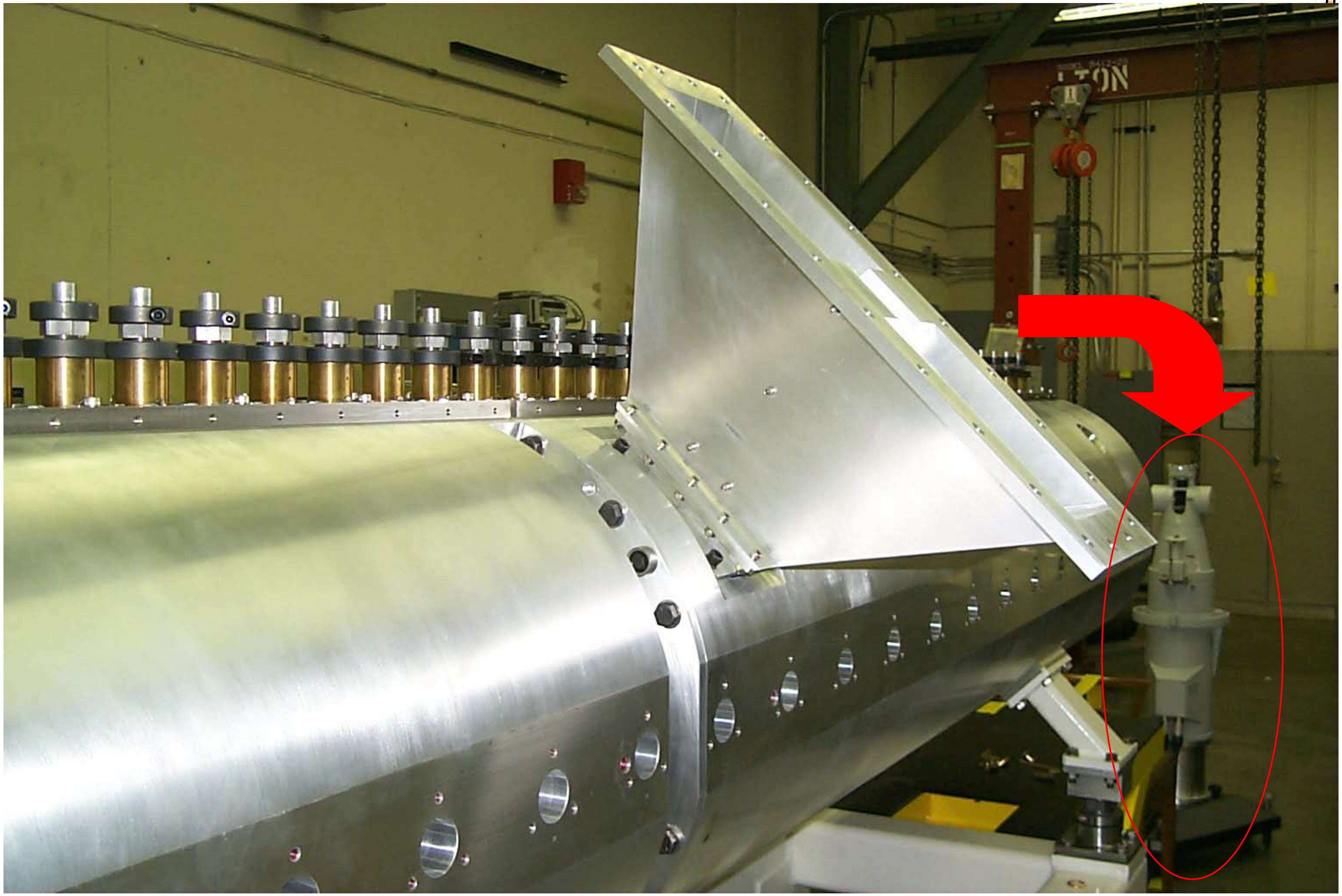
- **Adjust position of drift tube to match co-ordinates predicted by solid model**

- **Repeat measurement for opposite side fiducial and iterate**

USING LEICA LASER TRACKER TO ALIGN DTL COLD MODEL



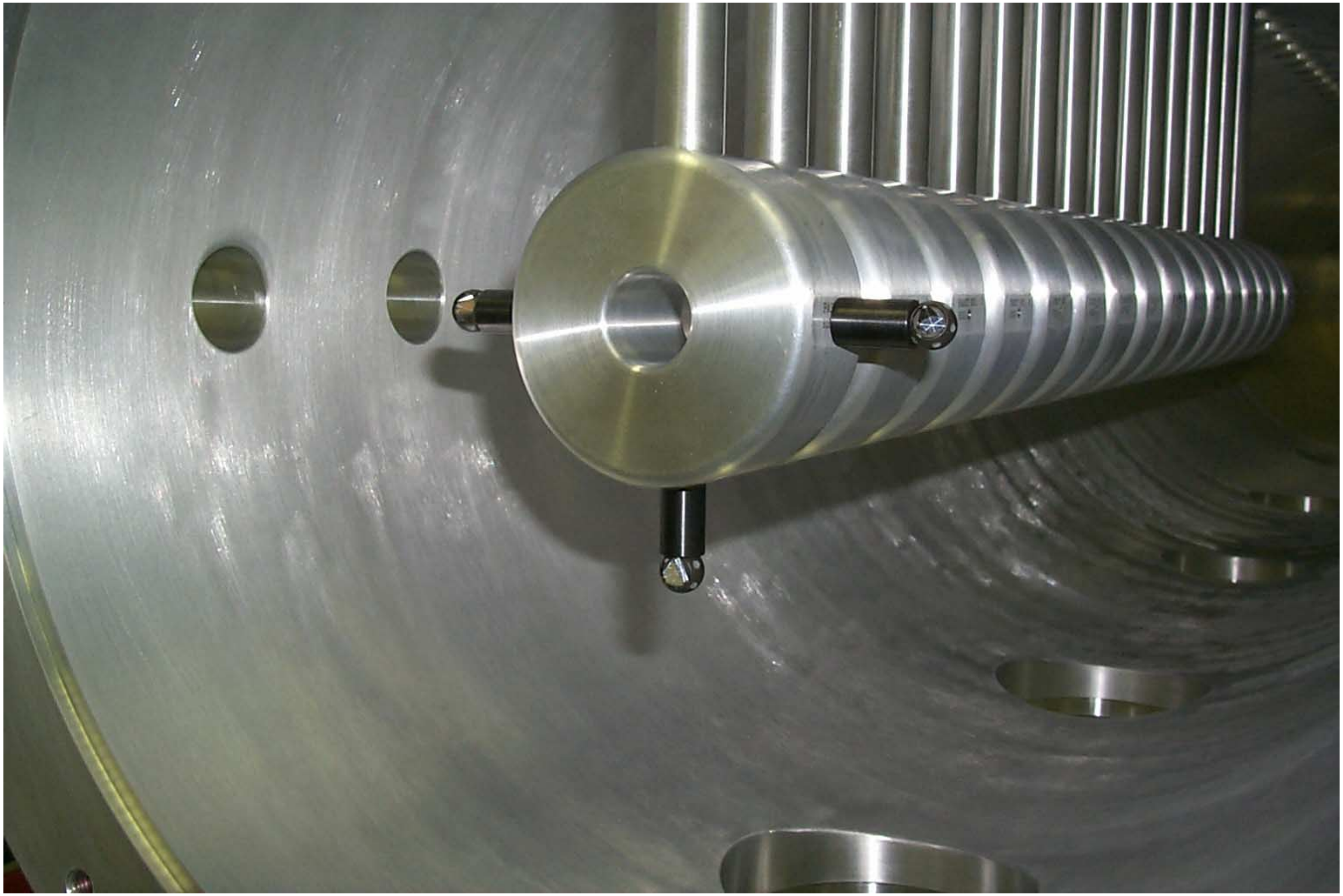
LASER TRACKER IN POSITION TO ALIGN DRIFT TUBES



Drift tubes being installed one at a time in succession

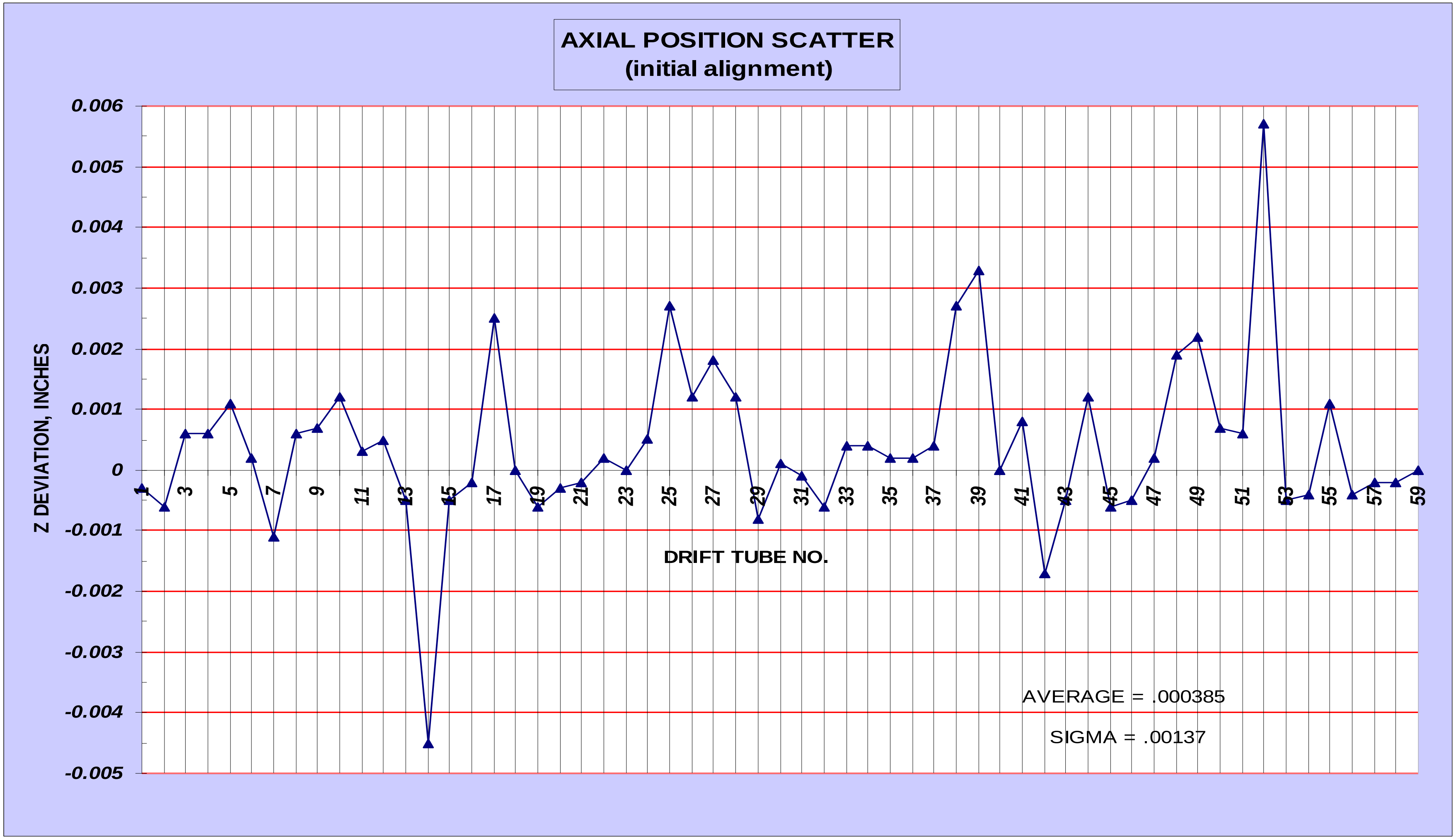
ENDWALL REFERENCE TARGETS AND FIRST DRIFT TUBE WITH TARGETS

16TH DRIFT TUBE WITH ALIGNMENT TARGETS

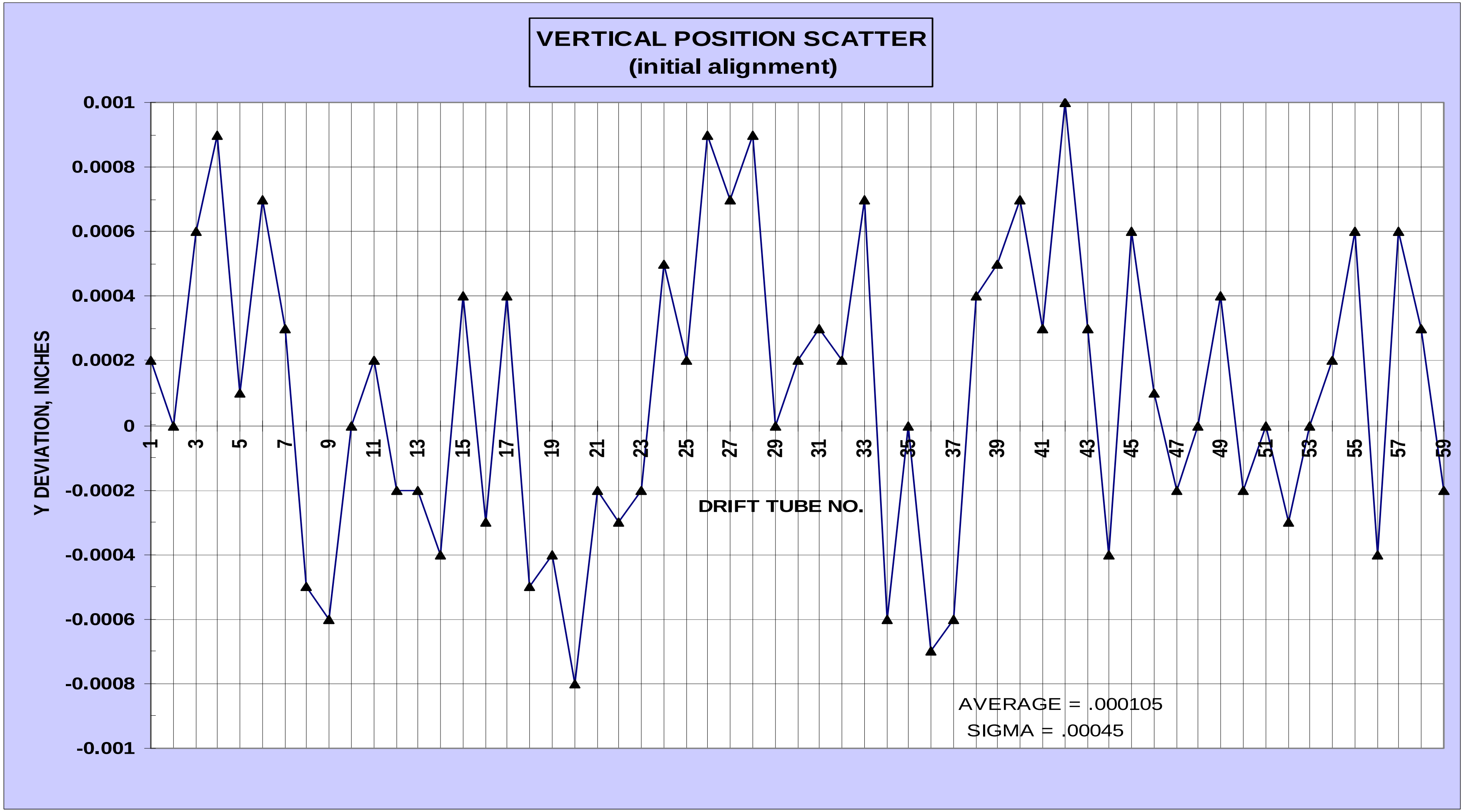


COMPLETED INSTALLATION AND ALIGNMENT OF 59 DRIFT TUBES

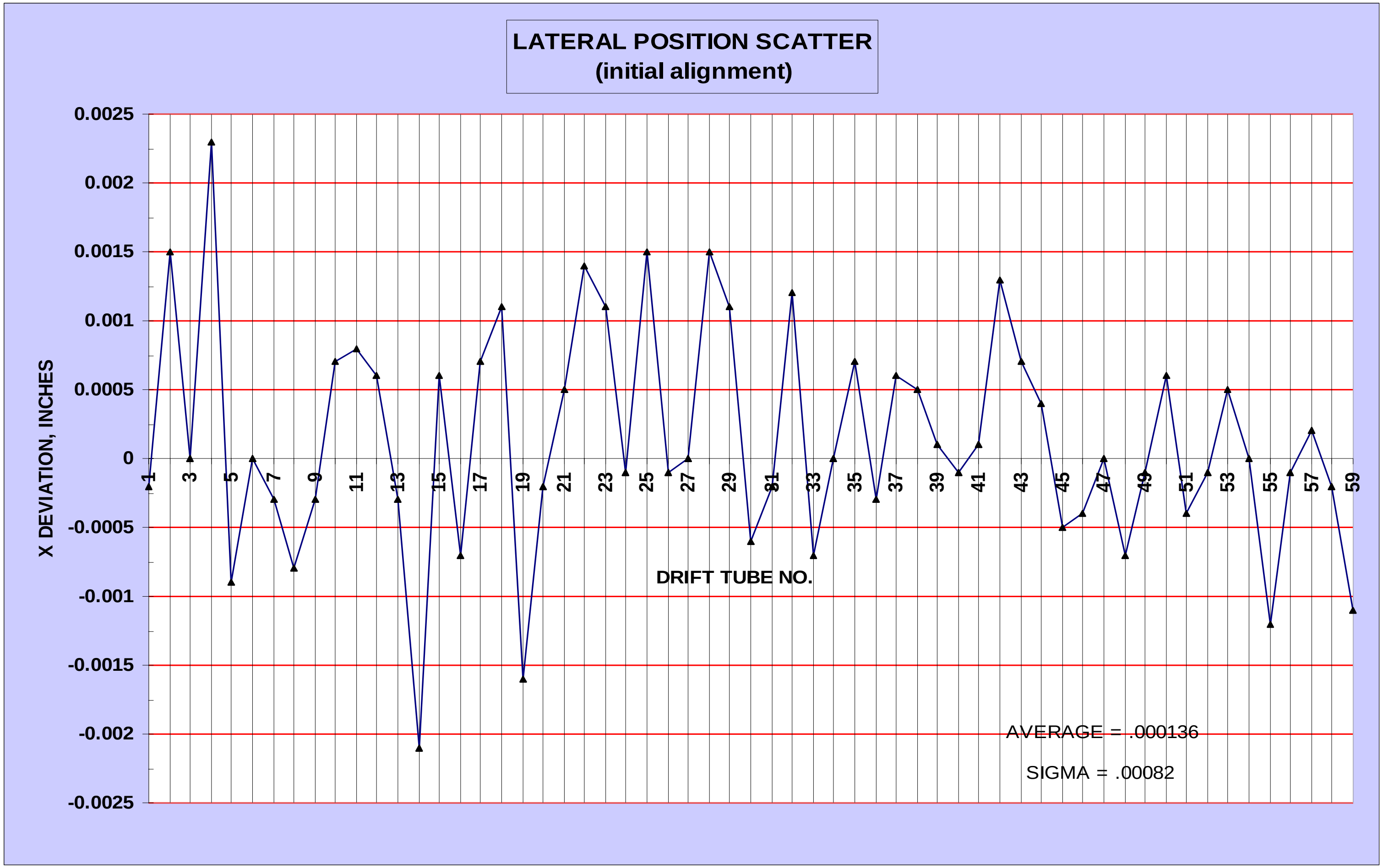
INSTALLED POSITION OF DRIFT TUBES



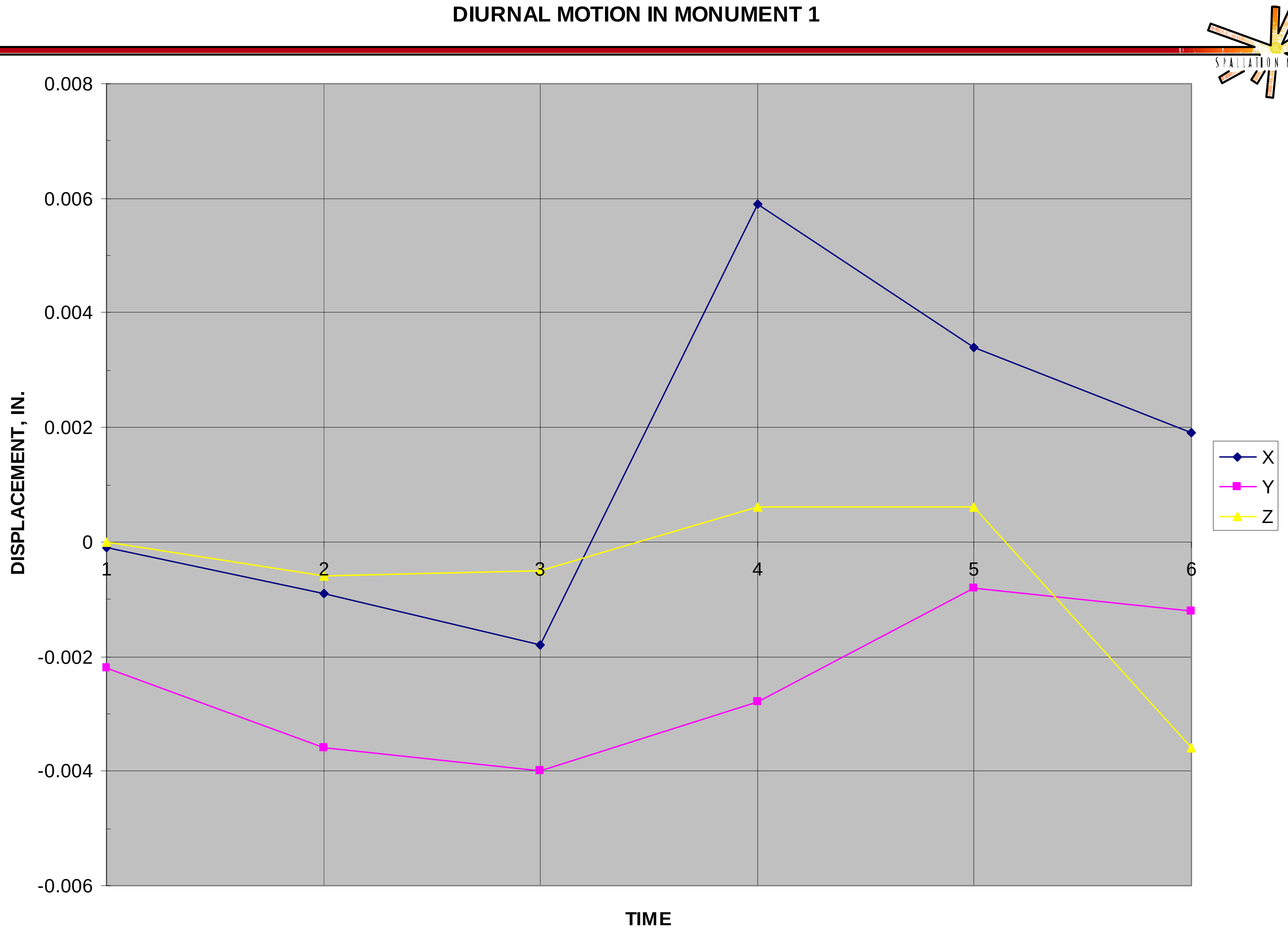
INSTALLED POSITION OF DRIFT TUBES



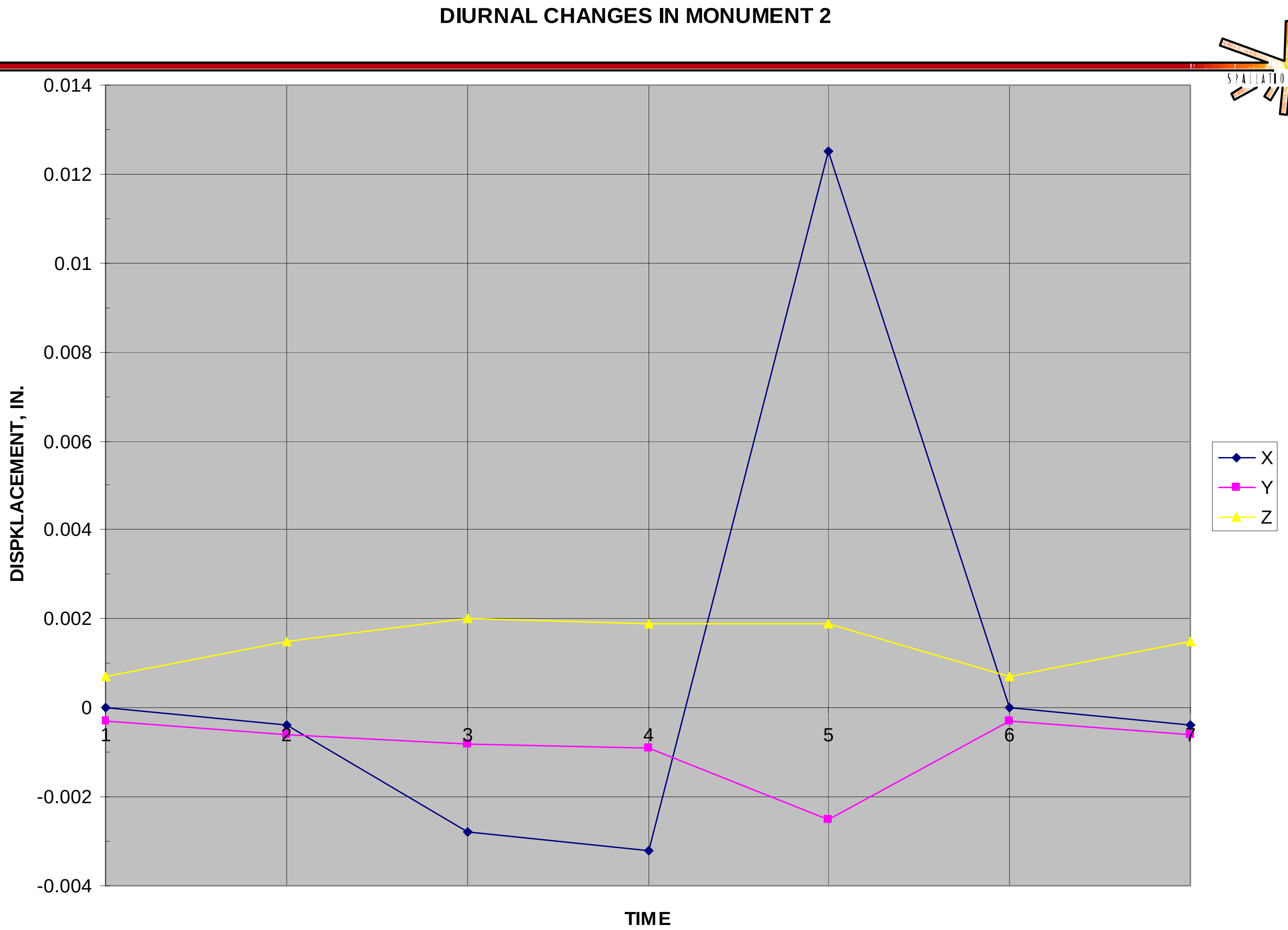
INSTALLED POSITION OF DRIFT TUBES



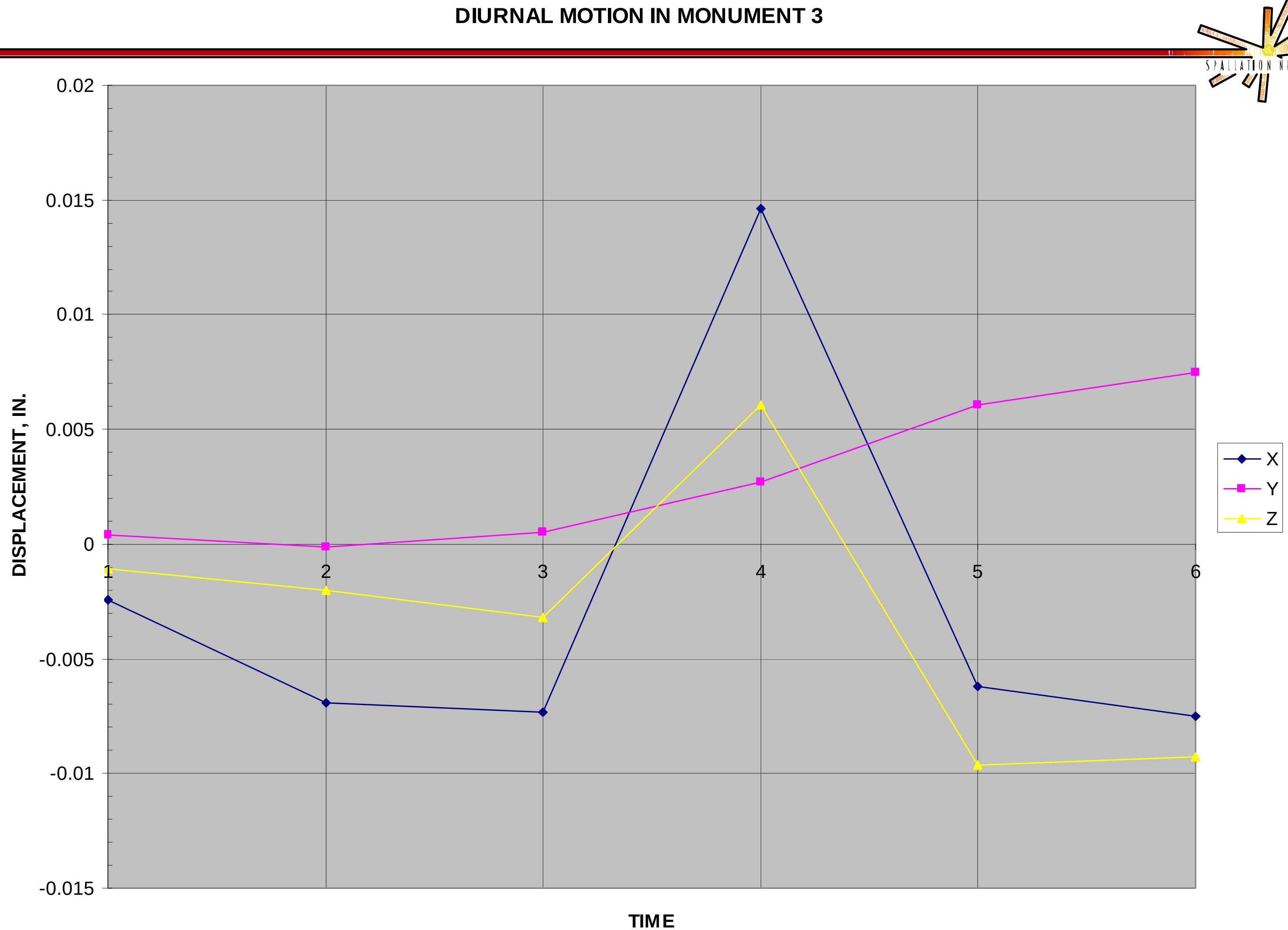
ETL FACILITY STABILITY



ETL FACILITY STABILITY

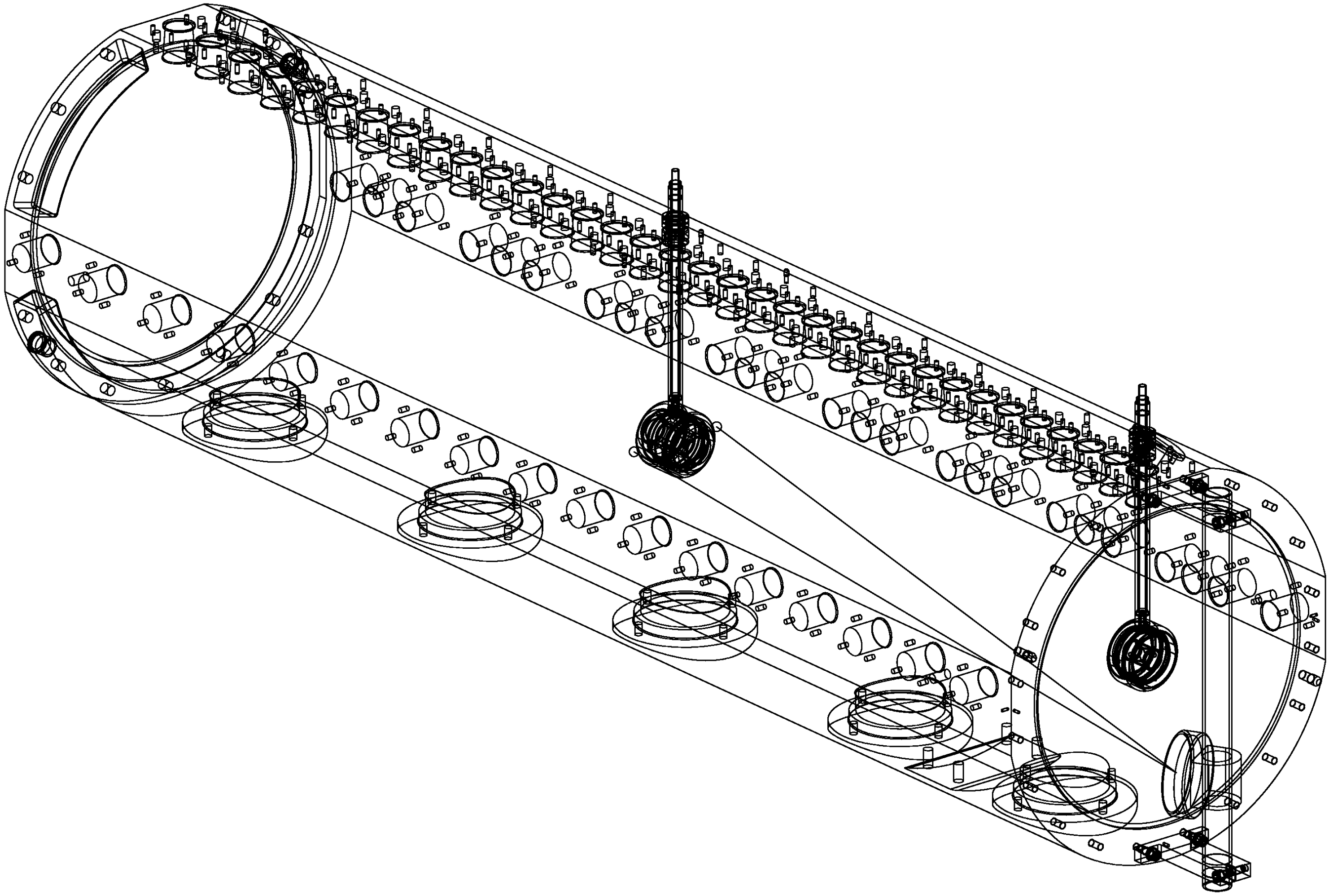


ETL FACILITY STABILITY



ON-GOING WORK

INVESTIGATION OF TURN MIRROR FOR DRIFT TUBE ALIGNMENT IN THE BEAM LINE



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Assembly at LANL and ORNL

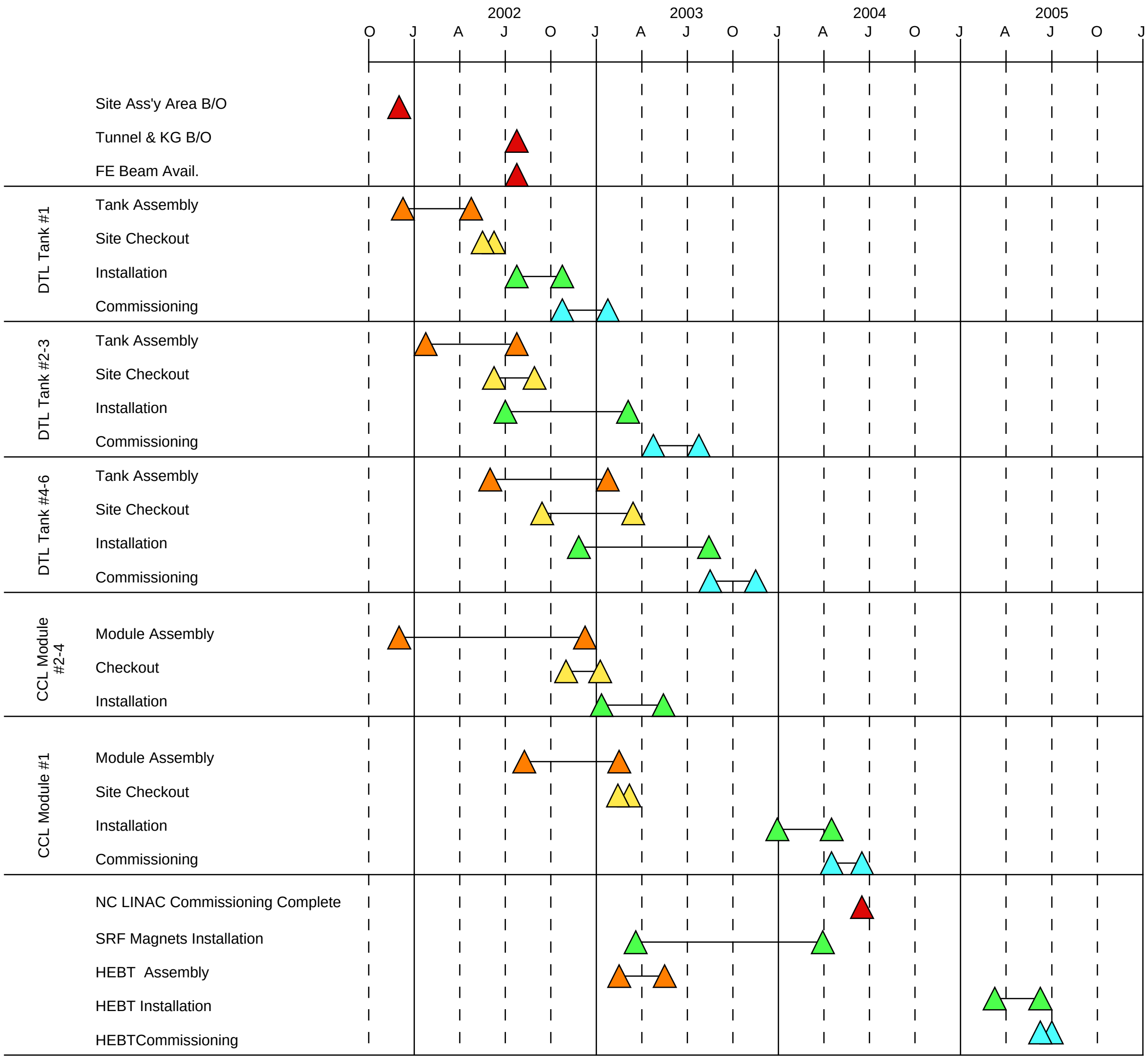
Installation at ORNL

Schedule Summary

Assembly & Installation Philosophy

- **Major tank assembly, initial alignment and tuning performed at LANL.**
- **Components are shipped as complete, tested subassemblies from the vendor and LANL to receiving at SNS (Site or RATS Building).**
- **The objective is to minimize tasks in the tunnel to reduce the possibility of equipment damage.**
- **The final assembly of each tank is completed and each tank is inspected and verified to meet quality requirements.**
- **Equipment handoff to SNS-ASD for installation.**
- **Criteria for assembly and installation:**
  - Schedule
  - Sequence of commissioning
  - Resource limitations (key tuning personnel)
  - Requirement for handoff to ORNL for installation

Assembly, Installation & Commissioning Sequence



System Level Design Philosophy

- **The unit structure is each individual Tank (6 total).**
- **To the extent practicable all external system connections will be made to headers or junction boxes on the support structure. These include:**
  - Water resonance control cooling lines (header)
  - Resonance control cooling instrumentation lines
  - Magnet cooling lines (header)
  - Steering dipole magnet power (J-box)
  - Vacuum instrumentation and controls (J-box)
- **Exceptions to this are:**
  - Beam Position Monitor (BPM) diagnostics connections
  - HV cable to Ion Vacuum pumps
  - RF power phase control detection loops

Major Assembly Activities - LANL

- Receiving inspection of components.
- Position tank on stand.
- Install tank cooling.
- Install and connect cooling to DTs and complete DT alignment.
- Install Low Power Post Couplers (LPPC) and Low Power Slug Tuners (LPST) and complete tuning.
- Remove LPPCs and LPSTs and measure for production units.
- Complete the manufacturing of the copper STs and PCs.
- Install Endwalls, PCs and STs.
- Complete tuning and documentation.
- Closure and leakage testing.
- Ship to ORNL.

Major Activities - Vendors

- Competitive bid from qualified suppliers with quality programs or demonstrated capability.
- Source inspection, with first article acceptance at vendor.
- Fabricate water cooling skids & ship direct to SNS.
- Commercial vacuum equipment ship direct to SNS.
- Commercial computers and controllers ship direct to SNS.
- Power supplies for Electromagnet Dipoles (EMD) ship direct to SNS.
- Rack fabrication location TBD (either commercial or RATS).

Resources

- The assembly team for LANL work:

Function	Resource	Staff	Task duration yrs	Man yrs
Alignment	Alignment Engineer	1	1	1
	Optical (L/T) Technician	1	1	1
	Mechanical Technician	1	1	1
Tuning	Cavity Physicist	1	1.3	1.3
	RF Technician	1	1.3	1.3
	Mechanical Technician	1	1.3	1.3
	Designer	1	1.3	1.3
	Total			8.3

Space & Equipment

- **The following facilities are needed for the initial assembly**
  - Space w/ temperature & vibration controlled environment.
  - Electrical power for network analyzer and laser tracker.
  - Ready access to machining and metrology facilities.
  - Access to cavity physics support personnel.
  - Provision for final phase of manufacturing of the slug tuners and post couplers.
- **The North side of Area A at LANSCE and an alternative commercial space in Albuquerque meet these criteria.**

Major Assembly Activities - SNS Site

- Material arrives for receiving inspection at the RATS building.
- The components for one complete tank are scheduled to arrive approximately every 6 to 8 weeks starting in April 2002.
- Drift tube alignment verification & bead-pull measurement.
- Assembly and attachment of peripheral components.
- Final acceptance testing.
- Rigging for transport to tunnel.
- Staffing:

Resource	Staff	Task duration yrs	Man yrs
Mechanical Technician	1	1	1
QA Technician	1	1	1
Alignment Engineer	1	1	1
Total			3

Assembly Activities - SNS Site

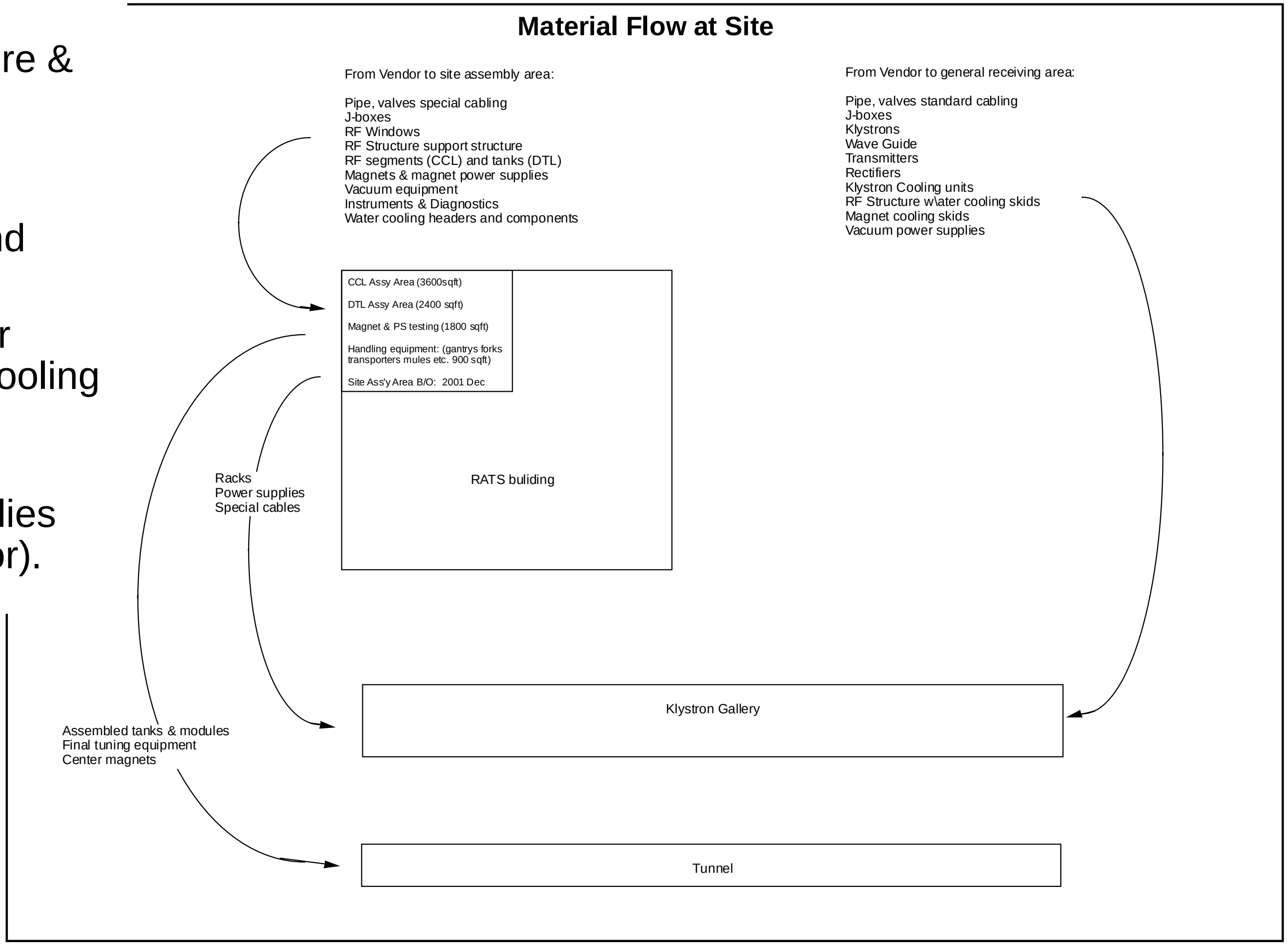
- LANL ships the tanks sealed & with an inert atmosphere to SNS.
- Containers are unloaded with forklift or crane at the RATS building.
- A set of floor-mounted steel pads are located in the assembly bay that allow the steel support structure to be solidly fastened to the floor. The floor is surveyed, and the pads machined to thickness and anchored to provide a flat and level baseline for tank final assembly.
- Tank cooling system is connected to the water system test cart. Temperature and cooling is connected to the test stand rack and the temperature of the module is brought to operational level.
- The tank electrical properties are evaluated by bead-pull.
- The drift tube alignment of each tank is verified optically.

Assembly Activities - SNS Site

- **Assembly of the other peripheral components is completed.**
  - Vacuum equipment & instrumentation.
  - Flow and temperature instrumentation and cabling.
  - Remaining cooling water connections.
  - Electrical power (EMD).
  - Diagnostics.
- **The final inspected of each tank is completed and each tank is verified to meet quality requirements.**
  - Vacuum leakage verification.
  - Water cooling system leakage and flow tests.
  - EMD continuity verification.
  - Instrumentation and diagnostics continuity verification.
- **Each tank is loaded onto a transporting trailer (type and design TBD) and transported to the HEBT access point unloading area on site.**
- **Receiving inspection of other equipment.**

Space & Equipment at ORNL (RATS)

- **Needed for checkout at ORNL:**
  - Space w/ temperature & vibration controlled environment.
  - Electrical power for network analyzer and laser tracker.
  - Power and chiller for resonance control cooling system.
  - Power for testing of magnet power supplies (alt: testing at vendor).



Major DTL Installation Activities

- **Installation is constrained to start after commissioning of the Front End. Beam and space for Tank 1 is available from the Front End 2002 July 29.**
- **Components are transported as completed tanks from RATS.**
- **Completed tanks 1 & 3 staged in tunnel until Front End completed.**
- **Material arrives at the tunnel one complete tank every 6 to 8 weeks.**
- **The objective is to minimize tasks in the tunnel to reduce the possibility of equipment damage.**
- **Each tank is transported to the tunnel, positioned and aligned. All support systems are connected.**
- **RF technicians and engineers verify RF tuning at low power. The system is operated under local control during the RF conditioning phase.**

DTL Tank Transport Data

- **Tank 1**
  - 163.5” long (4.2 m)
  - 10600 lbs
- **Tank 2**
  - 283.7” long (6 m)
  - 14400 lbs
- **Tank 3**
  - 250” long (6.3 m)
  - 13400 lbs
- **Tank 4**
  - 252.5” long (6.4 m)
  - 13200 lbs
- **Tank 5**
  - 247.9” long (6.3 m)
  - 13600 lbs
- **Tank 6**
  - 249.5” long (6.3 m)
  - 13600 lbs

DTL Installation Activities

- **Actions required before the tanks are brought into the tunnel:**
  - Facility piping installed, flushed, pressure-tested and flow-tested with the water cooling cart in place.
  - RF wave guide installed up to the final flex section on the air side.
  - Cables and wiring installed, terminated to the facility junction boxes and continuity tested for correct location and cable integrity.
  - Steel floor mounting plates installed level, and surveyed to correct height.
  - Floor and walls vacuumed, mopped and free of dirt and grit.
  - Alignment monuments installed and mapped to site coordinates.
  - Temperature and air quality control established with the HVAC, and lighting installed.
  - Installation, alignment and acceptance testing procedures and documents complete, reviewed and released.
- **Emphasis is to minimize activities in the tunnel, particularly activities that occur on the "back-side" of the LINAC because of the risk for damage to the equipment with the difficult access situation.**

DTL Installation Activities

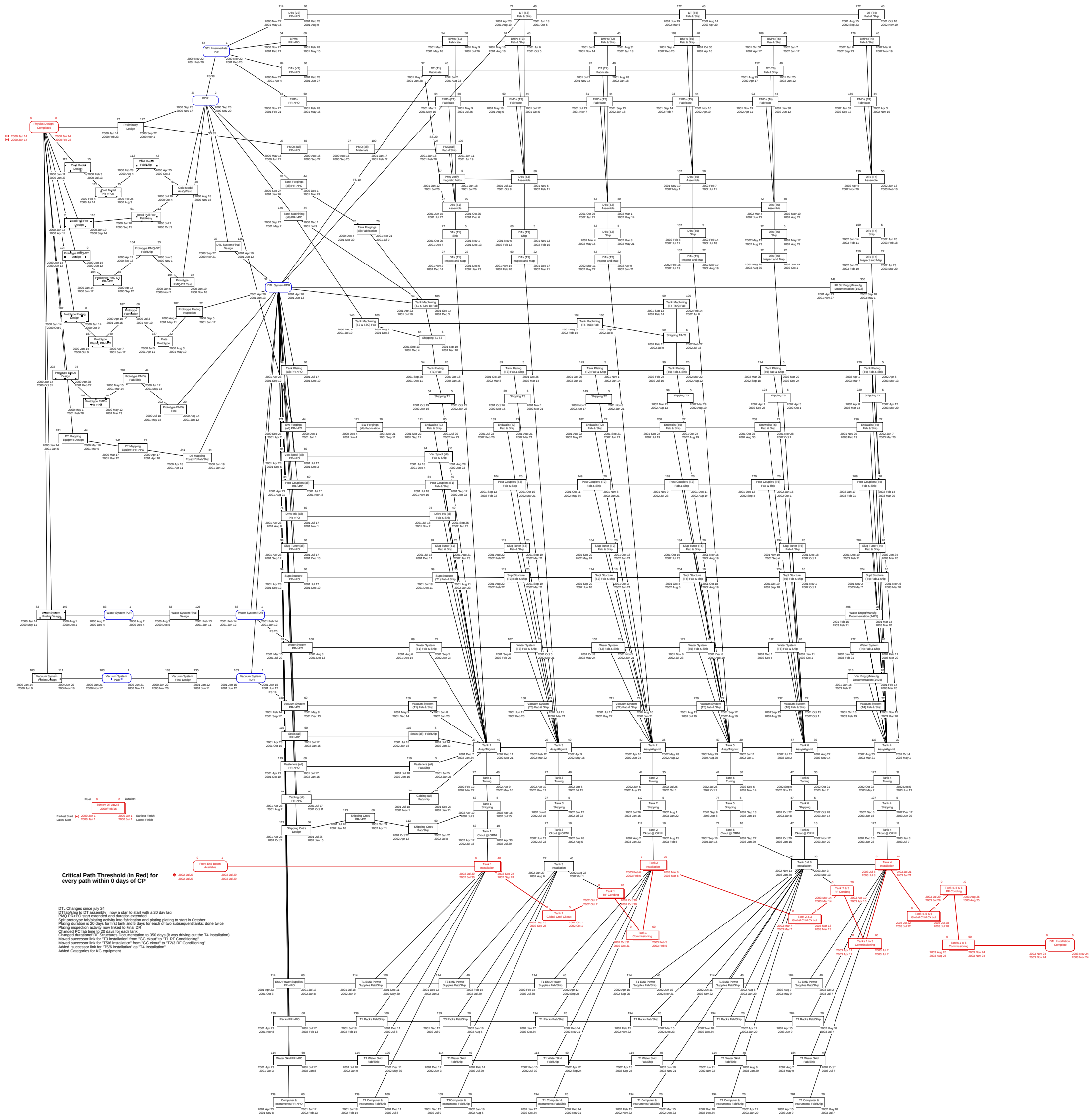
- **Activities in the tunnel will necessarily include:**
  - Mechanical placement and alignment of the tanks.
  - Final vacuum leakage tests on the tank assembly.
  - Connection of the water system to the facility piping.
  - Connection of wiring to the junction boxes.
  - Connection of RF wave guide to the window flanges.
  - Routing special cables (diagnostics and HV lines) to each tank.
- **RF technicians and engineers verify RF tuning at low power.**
- **The water system is engaged and water at operational temperature of the tank is circulated through the structure and allowed to thermally stabilize. Final alignment check is made with tank at operational temperature.**
- **Vacuum system is operated and the tank is pumped down to operational vacuum levels.**
- **RF operations may begin. The system is operated under local control during the RF conditioning phase.**

DTL Assembly and Installation Milestones

• Assembly of Tanks 1-6:	December 2001 to October 2002
• Installation of Tank 1 & 3 :	August 2002 to September 2002
• Installation of Tank 2:	February 2003
• Installation of Tank 5 & 6:	November 2002 to January 2003
• Installation of Tank 4:	July 2003
• DTL beam to CCL:	January 15 2004

- **Detailed schedule logic for Assembly and Installation have been prepared.**

Schedule - Design and Manufacturing



Schedule - Typical Tank Installation